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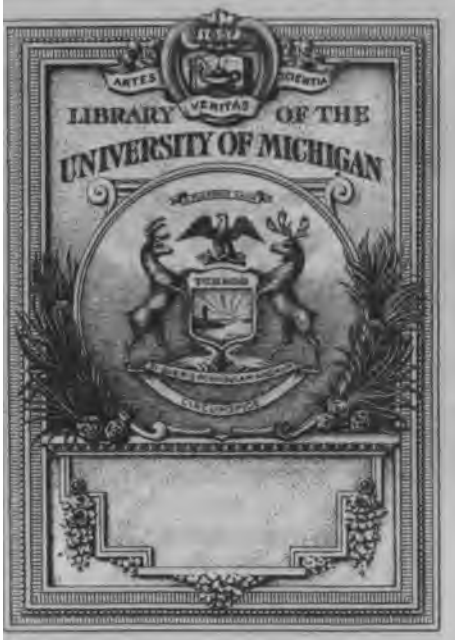
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Fred. W. Taylor.

PRESIDENT 1906
OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

THE AMERICAN SOCIETY OF
MECHANICAL ENGINEERS

TRANSACTIONS

VOLUME 28

NEW YORK MEETING, 1906

NEW YORK
PUBLISHED BY THE SOCIETY
NO. 29 WEST 39TH STREET
1907

11300

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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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MECHANICAL ENGINEERS

TRANSACTIONS

VOLUME 28

NEW YORK MEETING, 1906

NEW YORK
PUBLISHED BY THE SOCIETY
NO. 29 WEST 39TH STREET
1907

HONORARY COUNCILLORS

PAST PRESIDENTS OF THE SOCIETY

Thurston, R. H.	1880–1882	Died Oct. 25, 1903
Leavitt, E. D.	1882–1883	Cambridge, Mass.
Sweet, John E.	1883–1884	Syracuse, N. Y.
Holloway, J. F.	1884–1885	Died Sept. 1, 1896
Sellers, Coleman	1885–1886	Philadelphia, Pa.
Babcock, George H.	1886–1887	Died Dec. 16, 1893
See, Horace	1887–1888	New York, N. Y.
Towne, Henry R.	1888–1889	New York, N. Y.
Smith, Oberlin	1889–1890	Bridgeton, N. J.
Hunt, Robert W.	1890–1891	Chicago, Ill.
Loring, Charles H.	1891–1892	Brooklyn, N. Y.
Coxe, Eckley B.	1892–1894	Died May 13, 1895
Davis, E. F. C.	1894	Died Aug. 6, 1895
Billings, Charles E.[1]	1895	Hartford, Conn.
Fritz, John	1895–1896	Bethlehem, Penn.
Warner, Worcester R.	1896–1897	Cleveland, O.
Hunt, Charles Wallace	1897–1898	New York, N. Y.
Melville, George W.	1898–1899	Philadelphia, Pa.
Morgan, Charles H	1899–1900	Worcester, Mass
Wellman, S. T.	1900–1901	Cleveland, O.
Reynolds, Edwin	1901–1902	Milwaukee, Wis.
Dodge, James M.	1902–1903	Philadelphia, Pa.
Swasey, Ambrose	1903–1904	Cleveland, O.
Freeman, John R.	1904–1905	Providence, R. I.

[Note.—According to the Constitution, Article C 27, the five surviving Past Presidents who last held the office shall be members of the Council, with all the rights, privileges and duties of the other members of the Council.]

[1]Unexpired term of E. F. C. Davis

OFFICERS
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
1906

FORMING THE STATUTORY COUNCIL

PRESIDENT

FRED W. TAYLOR.....Philadelphia, Pa.

VICE-PRESIDENTS

S. M. VAUCLAIN.....Philadelphia, Pa.
H. H. WESTINGHOUSE.....Pittsburg, Pa.
GEORGE H. BARRUS.....Boston, Mass.
Terms expire at Annual Meeting of 1906

WALTER M. MCFARLAND.....Pittsburg, Pa.
EDWARD N. TRUMP.....Syracuse, N. Y.
ROBERT C. MCKINNEY.....New York, N. Y.
Terms expire at Annual Meeting of 1907

MANAGERS

GEORGE I. ROCKWOOD.....Worcester, Mass.
JOHN W. LIEB, JR.....New York, N. Y.
ASA M. MATTICE.....New York, N. Y.
Terms expire at Annual Meeting of 1906

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FRED J. MILLER.....New York, N. Y.
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FREDERICK M. PRESCOTT.....Milwaukee, Wis.
Terms expire at Annual Meeting of 1908

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SECRETARY

PROF. F. R. HUTTON.....No. 12 West 31st St., New York, N. Y.

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HONORARY COUNCILLORS

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SELLERS, COLEMAN	1885–1886	Philadelphia, Pa.
BABCOCK, GEORGE H.	1886–1887	Died Dec. 16, 1893
SEE, HORACE	1887–1888	New York, N. Y.
TOWNE, HENRY R.	1888–1889	New York, N. Y.
SMITH, OBERLIN	1889–1890	Bridgeton, N. J.
HUNT, ROBERT W.	1890–1891	Chicago, Ill.
LORING, CHARLES H.	1891–1892	Brooklyn, N. Y.
COXE, ECKLEY B.	1892–1894	Died May 13, 1895
DAVIS, E. F. C.	1894	Died Aug. 6, 1895
BILLINGS, CHARLES E.[1]	1895	Hartford, Conn.
FRITZ, JOHN	1895–1896	Bethlehem, Penn.
WARNER, WORCESTER R.	1896–1897	Cleveland, O.
HUNT, CHARLES WALLACE	1897–1898	New York, N. Y.
MELVILLE, GEORGE W.	1898–1899	Philadelphia, Pa.
MORGAN, CHARLES H	1899–1900	Worcester, Mass
WELLMAN, S. T.	1900–1901	Cleveland, O.
REYNOLDS, EDWIN	1901–1902	Milwaukee, Wis.
DODGE, JAMES M.	1902–1903	Philadelphia, Pa.
SWASEY, AMBROSE	1903–1904	Cleveland, O.
FREEMAN, JOHN R.	1904–1905	Providence, R. I.

[NOTE.—According to the Constitution, Article C 27, the five surviving Past Presidents who last held the office shall be members of the Council, with all the rights, privileges and duties of the other members of the Council.]

[1]Unexpired term of E. F. C. Davis

STANDING COMMITTEES

1906

FINANCE

MILTON P. HIGGINS (1)
E. D. MEIER (*Chairman*) (2)
ANSON W. BURCHARD (3)
ARTHUR M. WAITT (4)
EDWARD F. SCHNUCK (5)

MEETINGS

CHARLES DAY (1)
A. E. FORSTALL (2)
CHAS. WHITING BAKER (3)
CALVIN W. RICE (*Chairman*) (4)
GEO. R. HENDERSON (5)

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IRA H. WOOLSON (*Chairman*) (2)
JESSE M. SMITH (3)
HENRY D. HIBBARD (4)
E. I. H. HOWELL (5)

PUBLICATION

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C. J. H. WOODBURY (2)
HENRY H. SUPLEE (*Chairman*) (3)
WALTER B. SNOW (4)
D. S. JACOBUS (5)

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GEORGE J. FORAN (*Chairman*) (1)
THOS. R. ALMOND (2)
W. H. DOANE (3)
J. WALDO SMITH (4)
H. F. J. PORTER (5)

LIBRARY

W. D. FORBES (1)
FRED'K M. WHYTE (2)
GEO. F. SWAIN (3)
HENRY R. TOWNE (*Chairman*) (4)
AMBROSE SWASEY (5)

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FRED W. TAYLOR (*Chairman*) (1)
JOHN R. FREEMAN (2)
JOHN W. LIEB, JR. (3)
FRED J. MILLER (4)
F. R. HUTTON (5)

NOTE—Numbers in parentheses indicate length of terms in years.]

SPECIAL COMMITTEES

On Proportions for Standard Machine Screws

WILFRED LEWIS — C. C. TYLER
GEO. R. STETSON — JOHN RIDDELL
GEO. M. BOND — H. K. JONES

On a Standard Tonnage Basis for Refrigeration

D. S. JACOBUS — G. T. VOORHEES
A. P. TRAUTWEIN — PHILIP DE C. BALL
E. F. MILLER

On Society History

JOHN E. SWEET — HENRY H. SUPLEE
CHARLES WALLACE HUNT

On Local Sections

AMBROSE SWASEY — JESSE M. SMITH
CHAS. WALLACE HUNT — JOHN W. LIEB, JR.
F. R. HUTTON

On a Standard Code for Testing Gas Producers:
(To be appointed)

REPRESENTATIVES OF THE SOCIETY ON COMMITTEES

For Award of the John Fritz Medal

S. T. WELLMAN — JOHN E. SWEET
JAMES M. DODGE — HENRY R. TOWNE

On Union Engineering Building

CHAS. WALLACE HUNT — F. R. HUTTON
JAMES M. DODGE

On Joint Library Committee

AMBROSE SWASEY — HENRY R. TOWNE
HENRY H. SUPLEE

On National Fire Protective Association

JOHN R. FREEMAN — IRA H. WOOLSON

On the Fulton Centennial

GEO. W. MELVILLE — CHAS. H. LORING

On Government Advisory Board on Fuels and Structural Materials

P. W. GATES — W. F. M. GOSS
GEO. H. BARRUS.

SUMMARY OF MEMBERSHIP

SUMMARY OF MEMBERSHIP, DECEMBER 31, 1906.

UNITED STATES

	Membership		Membership
Alabama	10	Montana	12
Alaska	22	Nebraska	6
Arizona	1	New Hampshire	16
Arkansas	2	New Jersey	195
California	54	New Mexico	1
Colorado	21	New York	825
Connecticut	132	North Carolina	9
Delaware	13	North Dakota	1
Dist. of Columbia	26	Ohio	214
Florida	2	Oklahoma Ter	1
Georgia	16	Oregon	8
Hawaii	2	Pennsylvania	395
Illinois	150	Porto Rico	1
Indiana	44	Rhode Island	53
Ind. Territory	1	South Carolina	3
Iowa	8	Tennessee	8
Kansas	6	Texas	6
Kentucky	6	Utah	4
Louisiana	19	Vermont	12
Maine	15	Virginia	29
Maryland	29	Washington	5
Massachusetts	267	West Virginia	10
Michigan	73	Wisconsin	77
Minnesota	11	Wyoming	2
Missouri	48		

Total 2871

FOREIGN COUNTRIES

	Membership		Membership
Africa	17	Holland	1
Australia	6	India	2
Austria	1	Japan	5
Belgium	6	Mexico	7
Canada	22	Norway	1
China	1	Russia	5
Cuba	5	Scotland	3
England	40	S. America	9
Finland	1	Sweden	3
France	7	Switzerland	2
Germany	11	British W. Indies	1

Total 156

SUMMARY OF MEMBERSHIP

GEOGRAPHICAL

December 31, 1906.

Resident in Foreign Countries	156
Resident in United States	2871
Total	3027

BY GRADES

At the end of the fiscal year, September 30, 1906.

Honorary Members	17
Members	1983
Associates	265
Juniors	694
Total	2959

Life members included in total.

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NEW YORK MEETING

HELD ON DECEMBER 3, 4, 5 AND 6, 1906,
BEING THE ANNUAL MEETING AND THE
FIFTY-FOURTH MEETING OF THE SOCIETY

No. 1118

PROCEEDINGS OF THE NEW YORK MEETING

The Twenty-seventh Annual Meeting of the Society was held the first week in December 1906. The headquarters at 12 West 31st Street being inadequate for the anticipated attendance, the generous offer of the New York Edison Company of the use of its auditorium and reading room was accepted, and the meeting was held there this year, as was also the Annual Meeting of 1905.

The registration was the largest yet recorded, there being 1352 present, and the larger part of this number were members of the Society.

The professional sessions included a symposium on power plants, three papers on roof construction, and miscellaneous subjects, among which were subway ventilation, Venturi meters, elevator and rotary pump tests, a transmission dynamometer containing new features, a discussion of our present weights and measures and the metric system, a new mechanical engineering index, the plan used by an apprentice school now in successful operation, and the art of cutting metals.

TUESDAY EVENING SESSION

The first session of the meeting was held on Tuesday evening, December 4, when Mr. Frederick W. Taylor, the President of the Society, read an address "On the Art of Cutting Metals," which is probably the most remarkable contribution ever received by the Society, representing as it does the results of experiments made with many hundreds of tools, and which had required, during twenty-five years, the concurrent efforts of educated engineers and workingmen and the continued coöperation of some ten great industrial establishments at an expense of nearly $200,000.

Mr. Taylor made known for the first time these important investigations which had been kept from the public entirely through a sense of honor among the workingmen and coöperators; a remarkable record, since in most cases the promises of secrecy were merely verbal.

The report of the Tellers, William T. Bonner, Myron K. Rodgers and H. M. Lane, announcing the election of the following officers, was read:

President

FREDERICK R. HUTTON, NEW YORK	946
Scattering	22

Vice-presidents

J. W. LIEB, JR., NEW YORK	967
P. W. GATES, CHICAGO, ILL	958
ALEX DOW, DETROIT, MICH	963

Managers

A. J. CALDWELL, BRIDGEPORT, CONN	970
G. M. BASFORD, MT. VERNON, N. Y	964
A. L. RIKER, BRIDGEPORT, CT	964
Scattering	2

Treasurer

W. H. WILEY, NEW YORK	971
Scattering	1

Total ballots cast	1008
Ballots thrown out unsigned	33
Total ballots counted by tellers	975

The newly elected President, Dr. Frederick Remsen Hutton, Professor of Mechanical Engineering at Columbia University, was escorted to the Chair and presented to the Society by Mr. Charles Wallace Hunt, and Mr. Worcester R. Warner. They did not present the man, but the new presiding officer, for through Professor Hutton's twenty-three years of service as Secretary, he has become personally better known to the membership than any other man in the Society. The announcement of his election was greeted with loud applause, proclaiming the unanimity of the choice.

In a few remarks Professor Hutton expressed his appreciation of the honor bestowed upon him, and also his regret at resigning the more intimate helpful intercourse afforded during his long administration of the active services of the Society as its Secretary.

President Taylor resumed the chair, and adjourned the session.

The balance of the evening was spent as a social reunion.

WEDNESDAY MORNING SESSION

The morning session was devoted to the business affairs and to the discussion of the President's address "On the Art of Cutting Metals." A detailed account of the business transacted at this session is found elsewhere in these preliminary pages.

"On The Art of Cutting Metals" By Mr. F. W. Taylor, Philadelphia, Pa.

Discussed by,

Dr. W. H. Blauvelt, Syracuse, N. Y.; Mr. J. S. Bancroft, Philadelphia, Pa.; Mr. H. L. Gantt, Pawtucket, R. I.; Mr. W. Lewis, Philadelphia, Pa.; Mr. H. R. Towne, New York; Mr. J. T. Hawkins, Boston, Mass.; Mr. H. K. Hathaway, Germantown, Pa.; Mr. W. S. Huson, Derby, Conn.; Mr. J. M. Dodge, Philadelphia, Pa.; Prof. L. P. Breckenridge, Urbana, Ill.; Mr. O. Smith, Bridgeton, N. J.; Mr. Calvin W. Rice, New York.

Dr. J. T. Nicholson, Manchester, England; Mr. D. Adamson, Denton, Lancashire, England; Mr. J. E. Stead, Middlesborough, England; Mr. F. M. Osborn, Sheffield, England; Mr. H. C. H. Carpenter, Manchester, England; Mr. R. A. Skeggs, Sheffield, England; Mr. C. Codron, Paris, France; Mr. H. Le Chatelier, Paris, France.

Standard Proportions for Machine Screws, By The Committee

The report of the Committee on the Standard Proportions for Machine Screws was presented and the discussion read. The Committee desired, on account of numerous requests from large manufacturers of screws for a modification of some of the tables in the Committee's report, that the report should not be voted upon at this meeting. It was stated that they expect to present the final report at the Spring meeting in Indianapolis.

WEDNESDAY AFTERNOON SESSION

The Wednesday afternoon session was devoted to the Power Plant Symposium. The first paper being,

"On the Evolution of Gas Power," By Mr. F. E. Junge, Berlin, Germany.

Discussed by,

Mr. G. J. Rathbun, Toledo, O.; Mr. J. E. Johnson, Jr., Glen Wilton, Va.; Mr. W. D. Ennis, Schenectady, N. Y.; Prof. C. E. Lucke, New York,; Prof. A. J. Wood, State College, Pa.; Prof. H. Diederichs, Ithaca, N. Y.; Mr. R. E. Hellmund, Prof. R. H. Fernald, St. Louis, Mo.; Mr. C. G. Atwater, Flushing, L. I.; Prof. R. C. Carpenter, Ithaca, N. Y.; Mr. F. Firmstone, Easton, Pa.; Mr. R. E. Mathot, Brussels, Belgium.

"PRODUCER GAS POWER PLANT," BY MR. J. R. BIBBINS, PITTSBURG, PA.

Discussed by,

Mr. W. D. Ennis, Schenectady, New York.

"STEAM TURBINE CHARACTERISTICS," BY MR. HANS HOLZWARTH, HAMILTON, OHIO

Discussed by,

Capt. H. Riall Sankey, Westminster, England; Mr. W. A. Bantlin, Stuttgart, Germany.

"A HIGH DUTY AIR COMPRESSOR," BY PROF. O. P. HOOD, HOUGHTON, MICH.

Discussed by,

Prof. R. C. Carpenter, Ithaca, N. Y.; Mr. F. V. Henshaw, Brooklyn, N. Y.; Mr. G. H. Barrus, Boston, Mass.; Mr. S. A. Moss, Lynn, Mass.; Mr. W. L. Saunders, New York; Mr. W. Y. Lewis, Flushing, L. I.

"THE STEAM PLANT OF THE WHITE MOTOR CAR," BY PROF. R. C. CARPENTER, ITHACA, NEW YORK .

Discussed by,

Prof. C. C. Thomas, Ithaca, N. Y.; Mr. W. S. Johnson, Milwaukee, Wisconsin.

"BOILER AND SETTING," BY MR. A. BEMENT, CHICAGO, ILL.

Discussed by,

Mr. A. A. Cary, New York; Prof. L. P. Breckenbridge, Urbana, Ill.; Prof. William Kent, Syracuse, N. Y.; Mr. W. H. Bryan, St. Louis, Mo.; Prof. D. S. Jacobus, Jersey City, N. J.; Mr. J. M. Whitham, Philadelphia, Pa.; Mr. W. D. Ennis, Schenectady, N. Y.; Mr. E. A. Hitchcock, Columbus, Ohio; Mr. W. L. Abbott, Chicago, Ill.; Mr. E. McLean, New York.

After the session the members and guests made a tour of inspection of the new building of the Engineering Societies at 29 West 39th Street, New York.

WEDNESDAY EVENING SESSION

Wednesday evening had been left without assignments to permit of individual uses by the members, but the trip to the Sandy Hook Proving Grounds in which all the members were anxious to participate, caused the moving of the session scheduled for Friday morning to Wednesday evening.

The following papers were read,

"VENTILATION OF THE BOSTON SUB-WAY" BY MR. H. A. CARSON. BOSTON, MASS.

Discussed by,

Mr. W. Clifford, Jeannette, Pa.; Mr. W. B. Snow, Watertown, Mass.; Mr. S. Homer Woodbridge, Boston, Mass.; Mr. G. A. Soper, New York; Mr. C. H. Churchill, Roanoke, Va.; Mr. F. Fox, Westminster, England.

"FLOW OF FLUIDS IN VENTURI TUBES," BY MR. E. P. COLEMAN, BUFFALO, NEW YORK

Discussed by,

Prof. R. C. Carpenter, Ithaca, N. Y.; Prof. A. L. Williston, Brooklyn,; Mr. S. A. Moss, West Lynn, Mass.; Mr. C. Herschel, New York; Prof. C. E. Lucke, New York.

"TESTS OF A PLUNGER ELEVATOR PLANT," BY MR. A. J. HERSCHMANN, NEW YORK.

Discussed by,

Mr. R. P. Bolton, New York; Mr. W. H. Bryan, St. Louis, Mo.; Mr. F. M. Wheeler, Montclair, N. J.; Mr. E. S. Matthews, New York; Mr. T. E. Brown, New York; Mr. W. Y. Lewis, Flushing. L. I.

"TEST OF A ROTARY PUMP," BY PROF. W. B. GREGORY, NEW ORLEANS, LA.

Discussed by,

Prof. R. C. Carpenter, Ithaca, N. Y.; Mr. A. M. Lockett, New Orleans, La.

"IMPROVED TRANSMISSION DYNAMOMETER," BY MR. W. F. DURAND STANFORD UNIVERSITY, CAL.

Discussed by,

Prof. J. J. Flather, Minneapolis, Minn.; Prof. R. C. Carpenter, Ithaca, New York.

"A PLAN TO PROVIDE A SUPPLY OF SKILLED WORKMEN," BY MR. M. W. ALEXANDER, WEST LYNN, MASS.

Discussed by,

Mr. H. F. J Porter, New York; Mr. H. K. Hathaway, Germantown, Pa.; Mr. L. D. Burlingame, Providence, R. I.; Mr. Edward Robinson, Burlington, Vt.; Mr. M. P. Higgins, Worcester, Mass.; Prof. Gaetano Lanza, Boston, Mass.; Mr. C. F. MacGill, Pittsfield, Mass.; Mr. J. Knickerbacker, Troy, N. Y.; Prof. C. R. Richards, Lincoln, Neb.; Mr. F. W. Taylor, Philadelphia, Pa.; Mr. G. R. Henderson, New York; Mr. P. W. Gates, Chicago, Ill.; Prof. A. L. Williston, Brooklyn, N. Y.

THURSDAY MORNING SESSION

At the professional session beginning at 9.30 o'clock the following papers were read and discussed:

"SAW-TOOTH ROOF CONSTRUCTION," By MR. F. S. HINDS, BOSTON, MASS.

Discussed by,

Mr. W. B. Snow, Watertown, Mass.; Mr. S. M. Greene, Springfield, Mass.; Mr. L. H. Kunhardt, Boston, Mass.; Mr. J. E. Sweet, Syracuse, N. Y.; Mr. G. R. Henderson, New York.

"FERROINCLAVE ROOF CONSTRUCTION," BY MR. A. E. BROWN, CLEVELAND, OHIO.

Discussed by,

Mr. B. N. Bump, Syracuse, N. Y.; Mr. E. N. Hunting, Welchville, Maine.

"SAW TOOTH ROOFS FOR FACTORIES," BY MR. K. C. RICHMOND, PROVIDENCE, R. I.

Discussed by,

Mr. S. M. Greene, Springfield, Mass.; Mr. J. R. Fordyce, Atlanta, Ga.; Mr. L. H. Kunhardt, Boston, Mass.; Mr. H. V. Haight, Quebec, Canada; Mr. F. S. Hinds, Boston, Mass.

"WEIGHTS AND MEASURES," BY MR. HENRY R. TOWNE, NEW YORK.

Discussed by,

Mr. F. J. Miller, New York, N. Y.; Mr. L. D. Burlingame, Providence, R. I.; Mr. Oberlin Smith, Bridgeton, N. J.; Prof. William Kent, Syracuse, N. Y.; Mr. George Schuhmann, Reading, Pa.; Mr. H. H. Suplee, New York; Mr. G. W. Melville, Philadelphia, Pa.; Mr. J. M. Smith, New York, N. Y.; Mr. S. S. Dale, Boston, Mass.; Mr. F. A. Halsey, New York; Mr. J. S. Bancroft, Philadelphia, Pa.; Mr. Samuel Webber, Charlestown, N. H.; Mr. James Christie, Philadelphia, Pa.

"MECHANICAL ENGINEERING INDEX," BY PROF. W. W. BIRD AND PROF. A. L. SMITH, WORCESTER, MASS.

Discussed by,

Prof. L. P. Breckenridge, Urbana, Ill.; Mr. A. B. Clemens, Scranton, Pa.; Prof. William Kent, Syracuse, N. Y.; Mr. Henry Hess, Philadelphia, Pa.; Mr. L. D. Burlingame, Providence, R. I.

THURSDAY AFTERNOON

Through the courtesy of Mr. W. J. Wilgus, Vice-president of the New York Central and Hudson River Railroad Company, an invitation was extended to the members to visit the power station of the road at Port Morris. A large number availed themselves of the opportunity and the special train that left the Grand Central Station was crowded with engineers interested in an inspection of the plant which was to provide power for the electrification of the road.

THURSDAY EVENING

The usual reception was held at Sherry's. The members and guests were received by President F. W. Taylor and Mrs. Taylor, President-elect F. R. Hutton and Mrs. Hutton, Secretary Calvin W. Rice and Mrs. Rice. and the Treasurer, Major W. H. Wiley.

The reception was well attended and was a most successful affair. There was dancing in the reception room, and supper was served from ten to twelve o'clock.

FRIDAY

The members of the Society were the guests of the War Department. The Honorable the Secretary of War, William H. Taft, designated as his personal representatives to receive the Society at Sandy Hook, Brigadier General William Crozier, Chief of Ordnance, and Brigadier General Arthur Murray, Chief of Artillery. Both officers took the opportunity to explain to the visitors that part of the work under inspection about which they were specially qualified to speak.

About 800 members of the Society and their guests made the trip and witnessed perhaps the most unique demonstration of the power of the national coast defenses that it has ever been the privilege of any group of Americans to witness. Every variety of gun, from 10 inch down, was fired; mines were exploded, and ample opportunity afforded for the closest inspection of the inner workings of Fort Hancock with its mining casemates, sunken batteries, etc. The trip was made by train, and lunch was served on the cars both going and coming. It was undoubtedly one of the most enjoyable as well as instructive excursions ever made by the Society, and everyone who took part understands in what large measure we are under obligation to the War Department for this special courtesy shown the Society.

INVITATIONS

The members and guests were invited by the New York Electric Music Company to visit the plant of the Cahill Telharmonic System, an invitation which many of them were greatly pleased to accept.

The Automobile Show at the Grand Central Palace was open to the inspection of the members. The New York Edison Company invited the members of the Society to visit the two power stations, Waterside No. 1 and No. 2, where steam turbines of the largest size of the General-Electric-Curtis and Westinghouse–Parsons type were in operation.

APPENDIX

BUSINESS PRESENTED AND TRANSACTED AT THE WEDNESDAY MORNING, DECEMBER 5, SESSION OF THE ANNUAL MEETING

The following were declared elected to membership in the Society as the result of the ballot closing November 27.

Ahara, Edwin Hugh
Armstead, Frank Conant
Ayres, Gustave
Baker, George Otis
Beck, James Doughty
Billings, William Richardson
Brown, John Quincy
Buckley, John Francis
Bullock, S. A.
Caley, Charles J.
Chase, Henry Mayo
Clark, John Henry
Dam, William Valdemar
Decker, Edward P.
Dickinson, William Noble, Jr.
Dobson, Frank
Doelling, Louis Charles
Dupont, Thomas Coleman
Earthope, Joseph
Egbert, Charles Coggill
Entrekin, Norman Reese
Fenner, David Colton
Foller, Charles S.
Fuchs, Ernest
Gallagher, Robert Thomas
Goldie, M. McLean
Haddock, Edwin Joseph
Harper, John Lyell
Hartill-Law, A
Hayes, Frank H.
Heck, Robert C. H.
Hecker, Hugo Adelbert
Henderson, Richard
Hering, Rudolph
Hudson, Wilbur Gregory
Hunt, Leigh Anson
Jackson, Francis William
Johnson, Hobart Stanley
Jones, William Anthony
Kimball, Richard D.
King, Charles W. G.
Kipp, Alfred Ristine
Langer, Paul
LeConte, Joseph Nisbet
Linton, Robert
Lyle, Joel Irvine
McArthur, Arthur Royal
McEvoy, Dermot
MacCorquodale, Peter H.
MacGregor, Walter
Martel, Louis H.
Miller, Theodore Harry
Mowery, John Norris
Norton, Harold P.
Ramsden, John Thomas
Ryerson, William Newton

Saka, Tanoshi
Saunders, William Lawrence
Saxon, William
Schlachter, Carl H.
Seabury, Dwight
Search, Chas. Edwin
Shedd, Frank Edson.
Shirley, Robert
Simpson, Robert J. O.
Streenstrup, Peter Severin
Steinmetz, Charles P.
Stratton, James H.
Ulrich, Max Julius
Van Buskirk, Henry C.
Vernon, Percy V.
Wheeler, Charles Van Cise
White, George Henry
Wilson, Hugh Heathley
Winter, Oscar

PROMOTION TO MEMBERS GRADE

Arnold, Edwin Ebert
Austin, William Summer
Baylis, Arthur Raymond
Brinsmade, Louis L.
Brown James M.
Dixon, Horace Harcourt
Higgins, George F.
Hiles, Elmer Kirkpatrick
Hollander, Emanuel
Holmes, G. L.
Smart, Richard Addison.

ASSOCIATES

Anderson, Leslie Douglass
Ballin, Alfred Edward
Boyd, John J.
Catlin, Abel D.
Comstock, Chas. Warren
Corbin, George W.
Darling, Philip Grenville
Francis, Charles Albert
Garland, Claude Mallory
Goodwin, Leonard
Harman, Wm. Henry
Holt, Charles Parker
Hulbert, William Roswell
Laird, Wilbur Goodspeed
Sheppard, John Leffe, Jr.
Troutman, Howard Ellsworth
Truell, Karl Otto

PROMOTION TO ASSOCIATE GRADE

Bright, Holstein De Haven
Hall, Morris Albert
Hogle, Milton Ward
Proctor, Redfield, Jr.

JUNIORS

Adamson, Cecil F.
Barrett, Walter Aldrich
Bennett, Orvill G., Jr.
Beverley, Richard Carter
Bitterlich, Walter J.
Blankenhorn, George Stevens
Bursley, Joseph Aldrich
Bushnell, Leonard Theaker
Catlin, William Lyle
Coleman, Albert Edward
Cook, John Putnam
Forgy, J. Edmonds
Frechtling, Arthur George
Fritch, Robert P.
Gavagan, Edward, F.
Hackney, Wm. W., Jr.
Haldeman, Paul Collins
Hirschland, Franz Herbert
Holloway, Thurman Welford
Howell, John Jacob

Larkin, Everett Pierce
McDevitt, Frank J.
Michel, Arthur Eugene
Miller, Arthur Frederick
Noll, John J.
Paine, Henry Ellsworth
Parsons, William Claude
Peterson, Eric H. A.
Post, George Adams
Raymond, Herbert Emmons
Reed, Chester Turner
Renold, Charles Garonne
Rhoads, George Elwood
Russell, Walter Basford
Smith, Roy Harman
Spencer, William J.
Spotton, Arthur Knowlson
Van Nostrand, Leonard Greene
Vose, Fred Hale
Walsh, Thomas Joseph
Wardwell, Arthur Soper
White,, John Culbertson
Zapp, Louis Milton

SUMMARY

Election to full membership 75
Election to associate grade 17
Election to junior grade 43
Promotion to Members grade 11
Promotion to associate grade 4
Total number declared elected 150.

The loss by death from the membership during the current year is reported as follows:

Thos. R. Almond
P. H. Been
W. B. Bogardus
James Brady
Chas. A. Bragg
Jas. A. Burden
Louis Cassier
Geo. W. Catt
James Dredge
F. Grinnell
Ed. Thos. Hannam
I. V. Homes
John C. Kafer
J. R. F. Kelly
F. P. Loscher
A. C. McCallum
Max H. Miner
Wm. Painter
C. W. Phipps
A. J. Pitkin
Vernon H. Rood
Louis Schutte
F. J. Shaw
Geo. V. Sloat
Chas. I. Spier
J. E. Stevens
M. P. Wood

RESIGNATIONS

Resignations from the Society during the current year are as follows:

S. A. Capron
T. S. Leonhard
G. A. Morrison
Warren W. Chapin
Louis M. Clement
E. D. Searing
G. H. Stegman
Cyrus Robinson
Dwight Goddard
J. L. Hunter
G. W. Childs
J. I. Ayer
W. F. Evans
L. D. Crain
O. B. Stillman
G. A. Hutchinson
C. H. Robertson
G. F. Coleman
Alex. Delaney
E. A. Lewman
Edw. F. Tolman
Lawrence B. Melville
B. H. Dillon
James Atkins
Chris. C. Wais

AMENDMENTS TO THE CONSTITUTION

Notice of the amendments to the Constitution was as follows:
To add to the end of Section C 38 the following:

"The Council may also in its discretion appoint a person of the grade of Member to be an Honorary Secretary of the Society for a term not to exceed one year, but

he may be reappointed from year to year. He shall perform such duties as may be assigned to him by the Council which are in conformity with the Constitution and By-Laws, and with or without compensation as the Council may direct."

Mr. Charles Wallace Hunt in proposing the above amendment at the Chattanooga meeting said:

"It has been thought desirable that the Society should change one of the sections of its Constitution by putting in an additional clause whereby the Council should receive authority from the Constitution to appoint an Honorary Secretary. The proposition to create this office was referred to those members of the Society who as a Committee on Constitution and By-Laws prepared the present document under which the Society is at work, so that the wording of the proposed addition should be in accordance with the other parts of that instrument.

"I have in my hand the wording of an amendment to present under the provisions of Article C 57, which I present in writing for discussion and to come up for formal debate concerning its favorable consideration at the annual meeting in December.

"This proposed amendment is signed by myself and Messrs. Jesse M. Smith, D. S. Jacobus, George M. Basford, and R. H. Soule, who were the members of the original committee on Constitution and By-Laws."

AMENDMENT NO. 2

To add to Article C 45 after the words:

"House Committee" the words "Research Committee."

Mr. Jesse M. Smith in proposing the above amendment at the Chattanooga meeting said:

"I desire to offer an amendment to the Constitution looking towards the proposition to increase the scope and influence of the Society.

"It has been thought desirable that among the list of Standing Committees there should be one which in constitution and appointment would be similar to the other standing committees of the Society and which should be designated as the Research Committee.

"Such committee shall consist of five members, the term of one expiring at the end of each Society year, making the Committee as a body a permanent one, while changing in personnel from year to year. It is the purpose of the members presenting this proposed amendment to draft a set of By-Laws for the guidance of this Committee along the line of its work which will be presented to the Coun-

cil for action and adoption under the constitutional provision made in Article C 59. There are many lines of engineering in which the Society ought to be able to take a significant part and at present the mechanism for doing work along the lines of research is practically lacking. This amendment is presented by Messrs. Jesse M. Smith, C. W. Hunt, G. M. Basford, D. S. Jacobus, and R. H. Soule, the same members who presented the previous proposed amendment."

Under C 57 of the Constitution the above amendments will be presented for discussion and final amendment at the December meeting. If 20 votes are cast in favor of submission to the entire voting membership of the Society this action will be taken. The final vote on an amendment to the Constitution is by sealed letter ballot, closing at 12 o'clock on the first Monday of March following the discussion.

As there was no objection, these amendments were ordered submitted to the voting membership by letter ballot.

RESIGNATIONS

Under the provisions of the Constitution the Council presents to the Society at the Annual Meeting a report of the business year; together with the detailed reports of the Standing Committees.

The following appointments were made on committees. Mr. Ambrose Swasey, member of the John Fritz Medal Committee, to serve for a term of four years; Mr. Charles Wallace Hunt, to succeed himself as representative from the Society on the Board of Trustees of the United Engineering Society, to serve for a term of three years.

A vote of thanks was extended to the retiring President for his special service to the Society in introducing the new system of office methods as the result of unusual interest and at considerable personal expense.

A vote of thanks was extended to the incoming President for his services during the 23 years as Secretary of the Society. It was further moved that this vote of thanks be engrossed.

ANNUAL REPORT OF THE COUNCIL

After some months of negotiations a contract for the sale of the House of the Society, at No. 12 West 31st Street, New York City, has been completed. The purchase price is $120,000, on which we pay $1000 commission. Possession is to be given to the new owner on March 1, 1907, and $5000 has been paid down to bind the sale.

When the house was bought in 1890 it was valued at $60,000, which price the Society paid, leaving $33,000 in a first mortgage still held by the former owners. The Society has had the use of the house for nearly sixteen years and now disposes of it for practically twice its original value, and considerably more than twice the cash advanced. The Society paid $27,000 in cash in 1890, and retires from the undertaking with $86,000.

Under the agreement between the Society and the holding corporation of the building of the United Engineering Societies, each of the Founder Societies is to pay within 20 years one-third ($180,000) of the price of the land ($540,000), and in doing so to make a payment of at least one-twentieth ($9000) of the total each year. Under this agreement the Society has had to pay this year the sum of $9000 which becomes an investment in the new building. In addition to a like sum next year the Society will have to pay its pro rata of the operating expenses of the United Engineering Societies. When the proceeds of the sale of the house, 12 West 31st Street are received they will be applied to paying off a part of this loan.

LAND AND BUILDING FUND SUBSCRIPTIONS

It has been decided to raise a sum of money approximating $100,000 by subscription to pay off immediately the obligations incurred by the Society through this change of quarters. The matter has been referred to the Executive Committee and will be laid by them before the entire membership at an early date.

It had been the hope of the Building Committee that it would be possible to hold the annual meeting of the Society in the new building, but it has been decided not to utilize the building until it should be in a more advanced state of completion.

The members of the Council were present by invitation at the laying of the corner stone of the building on May 8. The ceremonies were very simple and informal, the laying of the stone being performed by Mrs. Carnegie.

THE SIMPLIFICATION AND STANDARDIZATION OF THE SOCIETY'S METHODS

Through the kindness of the President, Mr. Fred. W. Taylor, the services of a skilled expert in the matter of book manufacture and office procedure have been secured in order that the methods now in use might be simplified and the existing systems where the best possible, be standardized and recorded for the use of those interested. The services of Mr. Morris L. Cooke, Junior member of the Society, were secured by the President and he has been actively engaged in these duties since February 1.

For the carrying out of recommendations, which would be the outcome of this study and recording process, a special Committee on Standardization and Systematization was appointed, to consist of the President, the Secretary, and Mr. Fred J. Miller. Messrs. Charles W. Baker and Henry H. Suplee were appointed a special committee of experts, by the Standardization Committee, on the special problems of publication, and Messrs. Meier and Stillman, present and preceding chairmen of the Finance Committee, have acted also, to consider suggestions concerning the financial details of the Society's office.

PROFESSOR HUTTON'S RESIGNATION

At a meeting of the Council held on January 30, 1906, the letter from the Secretary of the Society was presented.

NEW YORK, January 29, 1906.

To the Council, The American Society of Mechanical Engineers

GENTLEMEN:

It may be known to some members of the Council that for several years I have had the thought in mind of resigning the Secretaryship of the Society on the completion of 25 years of service. I was first elected in March, 1883. My more recent thought has been that instead of waiting for a mere sentimental period to elapse, which would have meaning to myself alone, I might rather emphasize the more obvious culmination of my service to the Society by withdrawing at the time when the Society shall cross the threshold of its new home in the Engineering Building. It will then have been given to me to have wrought for the Society from the days of small beginnings, when I paid my own office rent and expenses, through the period of rented offices and of the ownership of the modest home in Thirty-first Street, and up to the opening of the days of larger opportunity in the splendid surroundings of the new enterprise.

It is wise, I am sure, that at the time of this external change, the Society should also make the internal change incident to securing as its Secretary one who will and can devote his entire time to the work and development of the Society.

It is well known to you that I have felt that I owe and must pay my first allegiance to the work of my professorship in Columbia University.

This being the case the Council should be advised far enough in advance so that the least embarrassment may be entailed by my withdrawal. I have thought it best to present this formal letter at the first meeting of the year, and to ask by it that proper action may be taken looking to the questions for the future which it raises. I ask that I may be relieved of the duties of the Secretaryship at the end of the current Society year, or at such other time thereafter as the Council may see fit to have this resignation take effect.

[Signed] F. R. HUTTON, *Secretary*

The Council gave extended consideration to the problems which were presented by this letter. It was the final outcome of these considerations that the Society should recognize that in the work of the Secretary's office of an engineering society, there were two distinct sets of duties or functions. One of these is the conduct of the meetings and the public functions of the Society and the other the direction of the executive work. The Council also decided that it would be, in their opinion, of the greatest importance, that the person to be chosen Secretary of the Society, on the expiration of the term of the present incumbent, should, if possible, be chosen as early in the autumn as possible so that he might familiarize himself with the duties under the guidance of the retiring Secretary and take them up with the least jar to the routine of the Society's work.

THE CHOOSING OF THE NEW SECRETARY

It was decided that under the Constitution the most direct method of accomplishing this purpose, was to appoint the candidate for the position of Secretary, to a position of Assistant to the Secretary, until the expiration of the Secretary's term. It was referred to the Committee on Standardization to consider nominations asked for from the membership and make a recommendation to the Council. From the considerable list submitted, the Council selected five names, having in its opinion the strongest claim for eligibility; and, finally, from that list, by unanimous vote, elected Mr. Calvin W. Rice, a Member of the Society, Assistant to the Secretary, his services in this position to begin as soon as possible after he could arrange to discontinue his present relations, and to end with the election of the successor to the present Secretary, after the annual meeting in December, 1906.

APPOINTMENTS

The Council filled the vacancy created by the election of Mr. F. W.

Taylor, Vice-President of the Society, to the Presidency, by electing Mr. G. H. Barrus of Boston to fill the office until the next annual election. Messrs. W. F. M. Goss, P. W. Gates, and G. H. Barrus, have been appointed representatives of this Society on an Advisory Board to coöperate with the Fuel Testing Board of the U. S. Geological Survey; and Mr. John R. Freeman has been appointed a member of the Special Committee of the National Fire Protection Association to report on the San Francisco disaster.

The thanks of the Pennsylvania Railroad Company have been received from Mr. A. J. Cassatt, President, for the coöperation of the Society and the services of its members in connection with the conduct of the Locomotive Tests at the St. Louis Exposition in 1904.

The city of Indianapolis, Ind., has been selected as the place for the Spring Meeting of 1907.

Three reunions of the members of the Society, resident within convenient distances of New York City were held, on the last Tuesday of the months of January, February and March. The speakers for these evenings were Mr. W. H. Bristol on "Thermo-Electric Pyrometers"; Mr. J. M. Dodge on "Some Practical Results of the Introduction of a Modern System of Shop Management"; and Mr. C. J. H. Woodbury, on the "Mechanical Engineering of Telephone Systems."

FINANCE COMMITTEE'S REPORT

The Finance Committee would report that by reason of the changes which have been made in certain important details of the Society's office and printing work a very substantial saving has appeared to be possible for the coming year, as compared with the expenditures of the current year. The accounts of the Society have been audited as usual and a detailed report of the New York Audit Company is on file in the office. The following are condensed reports and cover the fiscal year October 1, 1905, to September 30, 1906:

NEW YORK, November 1, 1906.

COLONEL E. D. MEIER, CHAIRMAN FINANCE COMMITTEE, THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 12 WEST 31st STREET, NEW YORK.

Dear Sir:

Agreeably to your request, we have audited the books and accounts of The American Society of Mechanical Engineers for the year ended September 30, 1906.

The results of this audit are presented, attached hereto, in three exhibits, as follows:

Exhibit A—Balance Sheet, September 30, 1906.

Exhibit B—Income and Expense Account, October 1, 1905, to September 30, 1906.

Exhibit C—Statement of Cash Receipts and disbursements, October 1, 1905 to September 30, 1906.

These exhibits are presented in tl form [illegible] d y[illegible] .

The condition of the books and accounts [illegible] cted [illegible] ice and the detailed information contained the[illegible]

We certify that the Balance Sheet [illegible] r [illegible] ed Inc [illegible] and [illegible] Acc [illegible] t, presented herewith, are true exhib [illegible] or the [illegible] and [illegible] tl [illegible] fo [illegible] the financial position of The Ameri an Soci [illegible] of [illegible] cal [illegible] on [illegible] ember 30, 1906, and the operations or the [illegible] ed.

Very truly yours,

THE AUDIT COMPANY OF NEW YORK

(Signed) E. T. Perine
General Manager

CASH ACCOUNT

RECEIPTS

To cash on hand Oct. 1, 1905		$26.36
To current receipts	$52,194.67	
To Trust Fund subscriptions	340.00	
To first payment on property 12 W. 31st St.	5,000.00	
To savings banks	5,000.00	62,534.67
		$62,561 03

DISBURSEMENTS

By completion Vol. 26 (1904–5)	$4,715.52	
By current disbursements	39,133.91	
By reduction land loan	9,000.00	
By interest on land loan	6,000.00	
By cash on hand Sept. 30, 1906	3,711.60	$62,561.03

INCOME AND EXPENSE ACCOUNT

INCOME

Dues	$40,081.25	
Initiation fees	486.38	
Sales	2,779.51	
Rentals	1,230.50	$44,577.64

EXPENSE

Transactions, Vol. 27	$13 284.58
Salaries	12,931.30
Office	2,415.59
Meetings	1,369.08
Membership lists	2,253.52

Circulars	2,079.47	
Membership development	764.34	
House	3,867.96	
Interest on mortgage	1,402.50	
Library	1,004.29	
Accounts written off	64.40	$41,436.93
Balance		3,140.71
		$44,577.64

BALANCE SHEET

October 1, 1906

ASSETS

Purchase contract, 31st Street property	$115,000.00	
Land and Building investment	23,462.80	
Furniture, book value	1,333.68	
Library, book value	12,987.07	
Plates	1,642.97	
Stock Transactions, etc	7,597.50	
Dues receivable	1,085.00	
Accounts receivable	1,810.68	
Advances	462.97	
Cash, trust funds	2,121.97	
Cash, available for current expenses	3,711.60	$171,80.24

LIABILITIES

Mortgage, 12 West 31st St	$33,000.00	
Reserved to complete Vol. 27	6,010.00	
Reserved accrued interest	350.00	
Advance payments	296.52	
Reserve Fund and Week's Legacy Fund	963.31	
Library Development Fund	1,509.94	
Trust Funds, M. E. L. A.	410.91	
Accounts payable	721.31	$43,262.61
Surplus		127,917.63
		$171,180.24

The above reports are made at such length as it is believed will be most convenient for the membership. The Committee will be glad at any time to provide members with more detailed information about any item which may not seem to be sufficiently covered in these summaries.

The following notes are offered as an aid to a fuller understanding of the financial reports and the accounting methods:

One per cent of the dues collected is appropriated to a Library Development Fund, the remaining 99 per cent is available for current expenses. Ten per cent of the initiation fees is available for current expenses, and the remaining 90 per cent disbursed on capital account only, as are life membership payments and the interest thereon.

Moneys to be expended on capital account only as well as trust funds are kept in savings banks.

Ten per cent book value furniture and fixtures is written off annually. The Library is inventoried at an assessed value fixed by experts several years ago, plus the value of acquisitions made since then; plates at the market value of the metal in them; Transactions and other stock at the estimated cost to reproduce.

Respectfully submitted,

E. D. MEIER, *Chairman*
MILTON P. HIGGINS
ANSON W. BURCHARD
ARTHUR M. WAITT
EDWARD F. SCHNUCK

MEMBERSHIP COMMITTEE'S REPORT

A circular letter was recently sent out to the membership, by the Secretary of the Society, under authority from the Council, asking for expressions of opinion as to the best means for improving the usefulness of the Society. Numerous replies urged that a more rigid scrutiny of the professional qualifications of the candidate for membership be made. The Membership Committee believes that the interpretation of the standard of professional requirements for membership in the Society, has never been more rigid than at present.

The Committee has met once a month during the past fiscal year beginning October 1, 1905, with average sessions of three hours each, and has studied the credentials of 400 applicants. One hundred and eighty of these have been passed to the Member's grade, of which number 41 were promotions from a lower grade. The total number passed to the Associate grade was 47, of which 14 were promotions from the Junior grade and 125 have been passed to the Junior grade.

The policy of the Committee has been to scan very critically the statement of the qualifications of each applicant for full membership, as well as those of his endorsers, and wherever a question of doubt existed as to qualification for the grade sought, action on the name has been deferred, and correspondence opened with a view of obtaining more detailed information, not only from his endorsers, but from the applicant himself, regarding his fitness and the character of his professional work.

It has been the distinct aim of the Committee to hold the standard of the Member's grade as high as it consistently could under the requirements of the Constitution, which makes demonstrated engineering ability a pre-requisite. If, in the opinion of the Committee, an applicant did not fully qualify as Member, he was promptly rated to the grade where he seemed to belong, and a courteous effort made through the Secretary to induce him to accept the Committee's rating. In the majority of cases this has been successful.

The Committee feels that there is often lack of consideration on the part of the members of the Society in the matter of endorsing candidates for membership. There is a tendency to endorse a candidate because he is a friend or good fellow, rather than because of his experience and ability as an engineer.

It is not unusual for the Committee to rate an applicant to the Associate grade upon the statement of his personal service sheet and find that he has five endorsers who regard him as entitled to the Member's grade, but give little or no reason for their actions. This places the Committee in a difficult and embarrassing position, which might be easily avoided if the members in endorsing a candidate would exercise more care, and consider seriously whether the candidate to their personal knowledge, actually possesses the qualifications and experience requisite to make him a Member under the Constitution.

The Committee contemplates requesting the Council to authorize more stringent interpretation of those clauses of the Constitution relating to membership, and to adopt means for obtaining more exact knowledge of the professional qualifications of the applicants.

It is a pleasure to report that during the past year by far the larger share of the applicants have been men of a high order of engineering ability and wide experience. This same tendency to betterment in quality is noticeable among the Associates and Juniors, particularly the latter, where nearly all the applicants are technical college graduates.

Respectfully submitted,

IRA H. WOOLSON, *Chairman*
JESSE M. SMITH
E. I. H. HOWELLS
HENRY D. HIBBARD
FRANCIS BLOSSOM

REPORT OF THE HOUSE COMMITTEE

The House Committee would report as follows:

Appropriation	$4,650.00
Net Expense	3,963.80
Decrease Net Expense from Appropriation	$686.20

DETAIL OF EXPENSE

Accounts	Detail	Total.
House Account—Operation.		
Gas and Electric Light	$539.71	
Fuel	181.88	
Janitor's supplies	196.16	
Laundry	417.07	
Wages	1,740.00	
Insurance	124.04	
Incidentals	246.53	$3445.39
Repairs and Renewals		
House	$94.14	
Furniture	328.33	422.47
Additions		
Furniture	95.94	95.94
Total		$3,963.80

The income from use of house by members and others has been $1230.50, a slight improvement over last year.

The net cost of operating the house for the year exclusive of repairs and renewals, depreciations and mortgage interest was $2214.89, whereas the cost inclusive of mortgage interest was $3167.39, and the total expense including the above and repairs and renewals and depreciations has been $4450.48.

The Committee has to report with regret the loss through death of two interested and useful members, Mr. John C. Kafer and Mr. Thos. R. Almond.

The Committee would call the attention of the Council to the fact that upon the transfer of the Society at the end of 1906 or the first months of 1907, to the building of the United Engineering Societies on 39th Street, the duties prescribed in the Constitution and By-Laws for the House Committee will either disappear entirely, or if such Committee should be continued, the wording of the By-Law covering their duties should be modified to conform to the new Constitution. The Committee understand from representatives of the United Engi-

neering Society which will have control of the building on 39th Street, that the Society will no longer have direct control of matters respecting the house maintenance, the service of janitors, cleaning and the like, together with repairs and additions to furniture, which are not exclusively office requirements.

The Committee have approved the provisional estimate of the architects of the building for new office furniture, and has put into its budget for the year an item of $3000 to cover this expenditure which will be made through the architects and their contractors and not through the Committee directly.

The Committee in making its recommendations for the budget, have estimated that it would be called on to meet routine expenditure from October 1, to March 1, at which time at the latest, it must forego the present quarters of the Society on 31st Street.

The expenditure for additions, both house and furniture, passes through the hands of this Committee, but the net expense of same is treated as an increase of assets and not as an expense through Income and Expense Account.

Respectfully Submitted,

GEORGE J. FORAN, *Chairman*
J. WALDO SMITH
W. H. DEANE
H. F. J. PORTER

REPORT OF THE COMMITTEE ON MEETINGS

We beg to report a successful meeting in the spring at Chattanooga, which was particularly well attended considering the situation, and the small number of members residing in the immediate vicinity.

An especial feature of the Committee's work is the preparation of a symposium of papers on engineering subjects, seeking to obtain a complete statement of the art on some one particular subject. The coming meeting in December is expected to be specially satisfactory and papers of extraordinary interest will be presented.

In coöperation with the Publication Committee the method of issuance of the Advance Papers in bound form was successfully tried at the Spring Meeting and has been improved further in the monthly "Proceedings," the first number of which was issued in September and will continue regularly for ten months of each year.

The suggestions sent in response to the circular letter of the Secretary, have been very carefully considered. We find that nearly ten per cent refer to the advisability of holding monthly meetings. It is

therefore the intention of the Committee to provide these during the winter. It is further planned to devote special attention at these meetings to the development of the acquaintanceship of members.

Other suggestions refer to the issuance of the "Proceedings," provision for discussion in advance, abstracting papers and limiting the time of presentation, so that more time may be given for discussion.

The Committee is grateful to those who have taken such interest as to make suggestions and is alive to all the opportunities of its work.

Respectfully submitted,

CALVIN W RICE, *Chairman*
CHARLES DAY
A. E. FORSTALL
CHAS. WHITING BAKER
GEO. R. HENDERSON

REPORT OF THE PUBLICATION COMMITTEE

The Publication Committee has held regular meetings during the year, examining critically the papers and discussions presented at the various meetings, dividing this work among the members of the Committee according to their special lines of work. With the exception of one paper, with its discussions, all the papers were approved for publication. One paper was sent back to the Committee on Meetings with the suggestion that it be presented again before the Society with certain verifications and explanations.

The Committee has had before it for consideration the general conduct of the printing of the Society, and has caused careful specifications for the printing of the Transactions to be framed, in order that comparative bids might be obtained. Under these specifications new bids have been obtained, and the work awarded in such a manner as will insure the productions in a decidedly better style than heretofore, at a marked reduction in cost. The figures relating to these bids and awards will be referred to by the Finance Committee.

The Committee has prepared instructions to contributors to the Society's publications rendering it practicable for papers to be prepared in such a manner as will enable the publication to be made to the best advantage, and also to cause the subjects to be presented in the clearest manner possible, rendering the discussions more general and useful. The Committee has also in hand the preparation of a standard style sheet, giving instructions to the printers as well as our own employees, as to the general make-up of the various publications

of the Society, including standard abbreviations, styles of type, reference authorities, etc., this work being still in hand.

The Committee has taken in hand the publication of the Year Book, and the Pocket List of members, with the result of a large economy in cost, and, it is believed, a material improvement in appearance.

Following out the plan of publishing the advance papers in quarterly installments, and thus securing the admission of the publication to the privileges of second-class mail matter, thereby effecting a large economy in postage, it has been deemed advisable to recommend the publication of the advance papers and other current information of the Society at more frequent intervals, in the form of Proceedings, this publication also replacing the numerous notices otherwise necessary, with their attendant cost of addressing and mailing, and placing in the hands of the members regular information concerning the work of the Society at a minimum cost, more promptly than otherwise possible. By the inclusion of notices of new books in the Proceedings, arrangements may be made with technical publishers by which the books can be secured for the library in exchange for listing in the Proceedings. The Year Book will probably also form one issue of the Proceedings, and thus be issued in the most advantageous manner.

The Committee has in hand a complete system of the examination of papers submitted for publication, arranging for the papers to be distributed among its members in such a manner that each paper, with its discussions, may be critically read by at least two members of the Committee, selecting those members most familiar with the subjects, the records of the committee showing, for subsequent reference, by whom the papers and discussions were examined. It is believed that by this procedure the value of the Transactions will be increased, while at the same time irrelevant and useless matter will be eliminated.

Certain changes in methods have already been instituted which have already showed savings. Thus:

Total Appropriation	$11,870.00
Total Net Expense	10,521.56
Decrease Net Expense from Appropriation	$1,348.44

Respectfully submitted,

HENRY HARRISON SUPLEE, *Chairman*
C. J. H. WOODBURY
WALTER B. SNOW
HARRIS TABOR
D. S. JACOBUS

REPORT OF THE LIBRARY COMMITTEE

The Committee reports that during the current Society year the matter of the procedure to be followed by the Library and its Committee on the removal to the new quarters, has been much under consideration. By reason of practical difficulties in reaching definite conclusions the Committee has not been particularly active in the matter of book purchases, in order that duplicating might be avoided among the three libraries of the Founder Societies. Two hundred and sixty-seven volumes have been added during the year.

It has appeared generally desirable that the three libraries should be operated in such way as to give the greatest benefit to those who may desire hereafter to consult them, while at the same time conserving with every degree of completeness and care the individual title to the ownership of the books.

For this reason expenditure under the library control has been kept down to the salary of the Librarian $600, the binding of exchanges and library expense, $484.62.

During the spring the Secretary's office sent to all the membership a circular requesting, from those interested, suggestions concerning the work of the Society and for making the work more useful and available to the membership at large. The suggestions received cover the following points:

1 Provision for research by a technical man, at the request and expense of members who may desire to have such work done in the Library.

2 Provision for research, at the request and expense of members, as to those who make or do certain things, thus constituting a "bureau of information" on professional matters.

3 Provision for the circulation of the books of the Library among non-resident members.

4 A traveling library for the use of Junior members or for sections of the Society, to be retained for use for one or two months.

5 The indexing of books and periodicals by loose-leaf or other practical system, so that members may have the Library Index up to date.

6 The sending of notices to all members as soon as the new technical books are published, with comment as to their value.

7 That the Library should contain copies of all patents as issued.

8 That a collection of lantern-slides should be provided from which a "loan selection" might be made to all members, college professors and others for their lectures.

9 Improved service in the Library; improved lighting; a wider range of engineering subjects.

10 The securing of biographical data and historical data of important installations has also been mentioned.

These recommendations have been brought before the Council of the Society for consideration and action. The decision as to some of them will turn on the amount of expense involved and funds available, but the Committee desires to take this opportunity to thank the contributing members for these valuable suggestions.

The Library has been open every day between the hours of 10 a. m. and 10 p. m., except on Sundays and Thanksgiving, Christmas and New Year, and except one-half of the months of July and August when it was closed for cleaning and overhauling. An average of 10 persons per day made use of the Library during the busy season and about one-half of this number during the vacation period of the summer.

The number of volumes in the Library, September 30, 1906, is as follows:

Books	9366
Pamphlets	3150
Maps	33

Respectfully submitted,

HENRY R. TOWNE, *Chairman*
W. D. FORBES
FREDK. M. WHYTE
GEO. F. SWAIN
AMBROSE SWASEY

FREDERICK WINSLOW TAYLOR

Frederick Winslow Taylor, President of The American Society of Mechanical Engineers, 1906.

Mr. Taylor was born in Germantown, Pa., in 1856. His primary education was obtained in this country, in France and in Germany. He was prepared at Phillips Exeter academy to enter Harvard at the age of eighteen with the class of 1874.

Perhaps fortunately for the best development of his natural talents, as he was about to enter college his eyesight became so much impaired that it became necessary for him to withdraw and change his educational plans.

He returned home with the determination to secure an apprenticeship to the engineering trades until his general health and eyesight should be sufficiently improved to permit his resumption of college studies.

An opportunity offered to apprentice himself to a small pump works in Philadelphia which he accepted. Here, on account of his previous educational advantages, he made rapid progress and was permitted by his employers to make special arrangements for completing a journeyman's course both in pattern making and the machinist trade.

He completed his four years apprenticeship during the dull period of 1878, and no opportunity offering to work at his trades, he accepted a position as laborer with the Midvale Steel Works.

With this company his industry and ability were soon recognized and rewarded. He was appointed shop clerk and afterward placed in charge of the tool room.

While in charge of the tool room his attention was drawn to the inefficient system and loss of time in allowing each man to grind his own tools. He received the approval of the company to designate one man for this duty, and not long afterward invented the Taylor grinder to accomplish the work more accurately and rapidly.

Having thus demonstrated his resources and abilities to meet emergencies, he was promoted from the position in the tool room through successive positions until six years from the time he started as a laborer he was chief engineer of the Midvale Steel Company. At

this time his experience and work had been such as to make him appreciate and desire to know more about the underlying principles of the science of engineering, so in 1880 he began to study at night the engineering course as required by Stevens Institute, and at the end of three years, in 1883, he obtained from Stevens the degree of M.E.

Mr. Taylor remained with the Midvale Steel Company until 1890, during which time he filled in a satisfactory manner each successive position assigned to him and had made many improvements in machinery and methods. In his passage through the shops he had studied the management and methods; he had developed his naturally keen powers of observation and his superior ability to analyze and draw deductions. Whenever possible he made direct application of his deductions until the plant as a whole bore the imprint of his labor.

As no definite data were available as to what a given mechanic should produce with a given tool and a given piece of work be began systematic studies, with the coöperation of the shop men and as a result the shop output was increased 200 to 300 per cent by an increase of pay of 25 to 100 per cent to the workmen.

Thus during this time he carefully observed and studied the problem of securing higher labor and tool efficiencies and laid the foundation of what later became his specialty "The development and application of the science of shop organization and management."

In 1890 he left the Midvale Steel Company and became manager of The Manufacturing Investment Company, operating large paper mills in Maine, where he remained until his three year contract expired.

He then began, as consulting engineer, to introduce his principles of organization and management into various establishments about the country. During this period and in connection with this work he made many valuable improvements and inventions, a large number of which he patented.

In 1898 The Bethlehem Steel Company found that their forge shop output was much greater than their machine shop capacity to handle this output. It was estimated that a new machine shop of sufficient capacity to keep up with the forge shop would cost one million dollars. At this juncture Mr. Taylor's success in producing increased shop efficiencies at other plants led the company to retain him to work out the problem.

Among the experiments made to increase the machine shop efficiency of the Bethlehem Steel Company were those on tool steel in conjunction with Mr. Maunsel White, leading to the discovery of the Taylor-White process of heat treatment, increasing the cutting efficiency of tool steel 100 to 200 per cent.

This process, and the tools treated by it, are used now in almost every machine shop in this country and also abroad. The essential qualities of all high speed tool steels are as first made by Mr. Taylor and Mr. White.

It has revolutionized machine shop practice and also caused changes in the machine tool industry. In the Bethlehem Steel Company's machine shop, where the discovery was made, the use of this steel and the improved shop methods of Mr. Taylor resulted in an increased production of .500 per cent, and instead of an increase in machine an increase was necessary in the forge shop.

Mr. Taylor presented his system of shop management to The American Society of Mechanical Engineers in a paper entitled "A Piece Rate System and Shop Management." He has also presented in his Presidential Address, December 1906, a most valuable and exhaustive monograph "On the Art of Cutting Metals," covering twenty-six years' experience.

In 1906 the University of Pennsylvania conferred the degree of Sc.D. upon Mr. Taylor. He was Vice-President of the Society 1904 and 1905, and President in 1906.

No. 1119

ON THE ART OF CUTTING METALS

By FRED W. TAYLOR, PHILADELPHIA
Member of the Society

PART 1

For Index and Definitions, see end of Part 1

1 The experiments described in this paper were undertaken to obtain a part of the information necessary to establish in a machine shop our system of management, the central idea of which is:

2 (A) To give each workman each day in advance a definite task, with detailed written instructions, and an exact time allowance for each element of the work.

3 (B) To pay extraordinarily high wages to those who perform their tasks in the allotted time, and ordinary wages to those who take more than their time allowance.

4 There are three questions which must be answered each day in every machine shop by every machinist who is running a metal-cutting machine, such as a lathe, planer, drill press, milling machine, etc., namely:

a WHAT TOOL SHALL I USE?

b WHAT CUTTING SPEED SHALL I USE?

c WHAT FEED SHALL I USE?

5 Our investigations, which were started 26 years ago with the definite purpose of finding the true answer to these questions under all the varying conditions of machine shop practice have been carried on up to the present time with this as the main object still in view.

6 The writer will confine himself almost exclusively to an attempted solution of this problem as it affects "roughing work"; *i. e.*, the preparation of the forgings or casting for the final finishing cut, which is taken only in those cases where great accuracy or high finish is called for. Fine finishing cuts will not be dealt with. Our principal object will be to describe the fundamental laws and principles which will enable us to do "roughing work" in the shortest time, whether the cuts are light or heavy, whether the work is rigid or elastic, and

The President's Annual Address, presented at the New York Meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

whether the machine tools are light and of small driving power or heavy and rigid with ample driving power.

7 In other words, our problem is to take the work and machines as we find them in a machine shop, and by properly changing the countershaft speeds, equipping the shop with tools of the best quality and shapes, and then making a slide rule for each machine to enable an intelligent mechanic with the aid of these slide rules to tell each workman how to do each piece of work in the quickest time.

8 It is to be distinctly understood that this is not a vague, Utopian result, to be hoped for in the future, but that it is an accomplished fact, and has been the daily practice in our machine shops for several years; and that the three great questions, as to shape of tools, speed, and feed, above referred to, are daily answered for all of the men in each shop far better by our one trained mechanic with the aid of his slide rule than they were formerly by the many machinists, each one of whom ran his own machine, etc., to suit his foreman or himself.

9 It may seem strange to say that a slide rule enables a good mechanic to double the output of a machine which has been run, for example, for ten years by a first-class machinist having exceptional knowledge of and experience with his machine, and who has been using his best judgment. Yet, our observation shows that, on the average, this understates the fact.

10 To make the reason for this more clear it should be understood that the man with the aid of his slide rule is called upon to determine the effect which each of the twelve elements or variables given below has upon the choice of cutting speed and feed; and it will be evident that the mechanic, expert or mathematician does not live who, without the aid of a slide rule or its equivalent, can hold in his head these twelve variables and measure their joint effect upon the problem.

11 These twelve elements or variables are as follows:

a the quality of the metal which is to be cut;
b the diameter of the work:
c the depth of the cut;
d the thickness of the shaving;
e the elasticity of the work and of the tool;
f the shape or contour of the cutting edge of the tool, together with its clearance and lip angles;
g the chemical composition of the steel from which the tool is made, and the heat treatment of the tool;
h whether a copious stream of water, or other cooling medium, is used on the tool;
j the duration of the cut; *i. e.*, the time which a tool must last under pressure of the shaving without being reground;

k the pressure of the chip or shaving upon the tool;
l the changes of speed and feed possible in the lathe;
m the pulling and feeding power of the lathe.

12 Broadly speaking, the problem of studying the effect of each of the above variables upon the cutting speed and of making this study practically useful, may be divided into four sections as follows:

13 (A) The determination by a series of experiments of the important facts or laws connected with the art of cutting metals.

14 (B) The finding of mathematical expressions for these laws which are so simple as to be suited to daily use.

15 (C) The investigation of the limitations and possibilities of metal cutting machines.

16 (D) The development of an instrument (a slide rule) which embodies, on the one hand, the laws of cutting metals, and on the other, the possibilities and limitations of the particular lathe or planer, etc., to which it applies and which can be used by a machinist without mathematical training to quickly indicate in each case the speed and feed which will do the work quickest and best.

17 In the fall of 1880, the machinists in the small machine shop of the Midvale Steel Company, Philadelphia, most of whom were working on piecework in machining locomotive tires, car axles, and miscellaneous forgings, had combined to do only a certain number of pieces per day on each type of work. The writer, who was the newly appointed foreman of the shop, realized that it was possible for the men to do in all cases much more work per day than they were accomplishing. He found, however, that his efforts to get them to increase their output were blocked by the fact that his knowledge of just what combination of depth of cut, feed and cutting speed would in each case do the work in the shortest time, was much less accurate than that of the machinists who were combined against him. His conviction that the men were not doing half as much as they should do, however, was so strong that he obtained the permission of the management to make a series of experiments to investigate the laws of cutting metals with a view to obtaining a knowledge at least equal to that of the combined machinists who were under him. He expected that these experiments would last not longer than six months.

18 With the exception of a few comparatively short periods, however, they have continued until the present time, through a term of about 26 years.

19 The writer wishes to call attention to the fact that in these first experiments he was far more fortunate than almost all of the experimenters who have investigated the subject since then, in

having at his disposal a comparatively large mass of uniform metal to work upon, and a comparatively large and powerful machine to work with, a 66-inch diameter boring mill and large locomotive tires made of hard tire steel of uniform quality having been used. He was also especially fortunate in having over him as president of the company, Mr. William Sellers, who, as is well known, was one of the most patient and broad-minded experimenters of his day. Mr. Sellers, in spite of the protests which were made against the continuation of this work, allowed the experiments to proceed; even, at first, at a very considerable inconvenience and loss to the shop. The extent of this inconvenience will be appreciated when it is understood that we were using a 66-inch diameter vertical boring mill, belt-driven by the usual cone pulleys, and that in order to regulate the exact cutting speed of the tool, it was necessary to slow down the speed of the engine that drove all of the shafting in the shop; a special adjustable engine governor having been bought for this purpose. For over two years the whole shop was inconvenienced in this way, by having the speed of its main line of shafting greatly varied, not only from day to day but from hour to hour. Before the two years had elasped, however, the writer had obtained such valuable and unexpected results from the experiments as to much more than justify all of the annoyance and expenditure, and soon after that he readily obtained permission to employ a young technical graduate to devote his whole time to the continuation of this work.

20 Mr. G. M. Sinclair, a graduate of Stevens Institute of Technology, devoted his entire time to this work from 1884 to 1887, when he left the employ of the company.

21 Mr. H. L. Gantt, also a graduate of Stevens Institute succeeded Mr. Sinclair in July, 1887, and has been interested with us in carrying on these experiments throughout their whole period.

22 In 1898 Mr. Maunsel White, of Bethlehem, another graduate of Stevens Institute, joined us and has been actively interested in our work up to this time.

23 Mr. Carl G. Barth, a graduate of The Technical School of Horten, Norway, joined us in 1899, and is still actively working on our investigations.

24 During these years we have consulted so freely together in all matters relating to these experiments that with few exceptions hardly a step has been taken which can be said to have originated with any one man. Therefore, whatever credit or blame may come to this work should be impartially divided among us. In writing this paper, then, no effort will be made to discriminate, as to the results which

have been obtained in our investigations, between the work of one man and another.

25 Mr. White is undoubtedly a much more accomplished metallurgist than any of the rest of us; Mr. Gantt is a better all-round manager, and the writer of this paper has perhaps the faculty of holding on tighter with his teeth than any of the others. It should be said, however, that Mr. Barth, who is a very much better mathematician than any of the rest of us, has devoted a large part of his time during the last years of these experiments to carrying on the mathematical work along the lines laid out, and that without his special ability and untiring energy our progress would have been much slower, indeed it is doubtful whether we should have ever reached the present solution of the problem without his aid.

26 In addition to the five men who have mainly directed and carried on this work, the writer wishes to acknowledge the most loyal and efficient aid and coöperation of many others who have assisted in the actual running of the machines and in recording or tabulating the data. Among these, he would particularly mention Mr. Dwight V. Merrick, Mr. D. C. Fenner, Mr. James Kellogg, Mr. Sidney Newbold, Mr. Joseph Welden. Mr. N. W. Wickersham, Mr. Edward Kneisley, and Mr. Leonard G. Backstrom.

27 Our experiments were continued in the works of the Midvale Steel Company until 1889, when the writer left their employ. Since then, these investigations have been carried on in various shops and at the expense of different companies. Among these, we would especially acknowledge our indebtedness to the Cramp's Shipbuilding Company, Messrs. Wm. Sellers & Co., the Link-Belt Engineering Company, Messrs. Dodge & Day, and, more than all, to the Bethlehem Steel Company.

28 In carrying on this work more than ten machines have been fitted up at various times with special driving apparatus and the other needed appliances, all machines used since 1894 having been equipped with electric drives, so as to obtain any desired cutting speed. The thoroughness with which the work has been done may perhaps be better appreciated when it is understood that we have made between thirty and fifty thousand recorded experiments, and many others of which no record was kept. In studying these laws we have cut up into chips with our experimental tools more than 800,000 pounds of steel and iron. More than sixteen thousand experiments were recorded in the Bethlehem Steel Company. We estimate that up to date between $150,000 and $200,000 have been spent upon this work, and it is a very great satisfaction to feel that those whose generosity has enabled

us to carry on the experiments have received ample return for their money through the increased output and the economy in running their shops which have resulted from our experiments.

29 Throughout the whole 26 years we have succeeded in keeping almost all of these laws secret, and in fact since 1889 this has been our means of obtaining the money needed to carry on the work. We have never sold any information connected with this art for cash, but we have given to one company after another all of the data and conclusions arrived at through our experiments in consideration for the opportunity of still further continuing our work. In one shop after another machines have been fitted up for our use, workmen furnished us to run them, and especially prepared tools, forgings and castings supplied in exchange for the data which we had obtained to date; and we have the best indication that they received full value for the money spent from the fact that the same company fitted up for us at intervals of several years three sets of apparatus, the additional knowledge obtained each time evidently warranting them in making the added outlay.

30 During this period all of the companies who were given this information, and all of the men who worked upon the experiments, were bound by promises to the writer not to give any of this information away nor to allow it to be published. Most of these promises were verbal; and in this day when there is so much talk about dishonesty and graft in connection with some of our corporations and prominent business men, it is a notable fact that through a period of 26 years it has not come to our knowledge that any one of the many men or companies connected with this work has broken a promise. The writer has his doubts whether any other country can produce a parallel record of such widespread good faith among its engineers and mechanics.

31 It seems to us that the time has now come for the engineering fraternity to have the results of our work, in spite of the fact that this will cut off our former means of financing the experiments. However, we are in hopes that the money required to complete this work may be obtained from some other source.

32 The writer has no doubt that many of the discoveries and conclusions which mark the progress of this work have been and are well known to other engineers, and we do not record them with any certainty that we were the first to discover or formulate them, but merely to indicate some of the landmarks in the development of our own experiments, which to us were new and of value. The following is a record of some of our more important steps:

33 (A) In 1881, the discovery that a round-nosed tool could be run under given conditions at a much higher cutting speed and therefore turn out much more work than the old-fashioned diamond-pointed tool.

34 (B) In 1881, the demonstration that, broadly speaking, the use of coarse feeds accompanied by their necessarily slow cutting speeds would do more work than fine feeds with their accompanying high speeds.

35 (C) In 1883, the discovery that a heavy stream of water poured directly upon the chip at the point where it is being removed from the steel forging by the tool, would permit an increase in cutting speed, and, therefore, in the amount of work done of from 30 to 40 per cent. In 1884, a new machine shop was built for the Midvale Steel Works, in the construction of which this discovery played a most important part; each machine being set in a wrought iron pan in which was collected the water (supersaturated with carbonate of soda to prevent rusting), which was thrown in a heavy stream upon the tool for the purpose of cooling it. The water from each of these pans was carried through suitable drain pipes beneath the floor to a central well from which it was pumped to an overhead tank from which a system of supply pipes led to each machine. Up to that time, so far as the writer knows, the use of water for cooling tools was confined to small cans or tanks from which only a minute stream was allowed to trickle upon the tool and the work, more for the purpose of obtaining a water finish on the work than with the object of cooling the tool; and, in fact, these small streams of water are utterly inadequate for the latter purpose. So far as the writer knows, in spite of the fact that the shops of the Midvale Steel Works until recently have been open to the public since 1884 no other shop in this country was similarly fitted up until that of the Bethlehem Steel Company in 1899, with the one exception of a small steel works which was an offshoot in personnel from the Midvale Steel Company.

36 (D) In 1883, the completion of a set of experiments with round nosed tools; first, with varying thicknesses of feed when the depth of the cut was maintained constant; and, second, with varying depths of cut while the feed remained constant, to determine the effect of each of these elements on the cutting speed.

37 (E) In 1883, the demonstration of the fact that the longer a tool is called upon to work continuously under pressure of the shaving, the slower must be the cutting speed, and the exact determination of the effect of the duration of the cut upon the cutting speed.

38 (F) In 1883, the development of formulæ which gave mathema-

tical expression to the two broad laws above referred to. Fortunately these formulæ were of the type capable of logarithmic expression and therefore suited to the gradual mathematical development extending through a long period of years, which resulted in making our slide rules, and solved the whole problem in 1901.

39 (G) In 1883, the experimental determination of the pressure upon the tool required on steel tires to remove cuts of varying depths and thickness of shaving.

40 (H) In 1883, the starting of a set of experiments on belting described in a paper published in Transactions, Vol. 15 (1894).

41 (J) In 1883, the measurement of the power required to feed a round-nosed tool with varying depths of cut and thickness of shaving when cutting a steel tire. This experiment showed that a VERY DULL TOOL required as much pressure to feed it as to drive the cut. This was one of the most important discoveries made by us, and as a result all steel cutting machines purchased since that time by the Midvale Steel Company have been supplied with feeding power equal to their driving power and very greatly in excess of that used on standard machine tools.

42 (K) In 1884, the design of an automatic grinder for grinding tools in lots and the construction of a tool room for storing and issuing tools ready ground to the men.

43 (L) From 1885 to 1889, the making of a series of practical tables for a number of machines in the shops of the Midvale Steel Company, by the aid of which it was possible to give definite tasks each day to the machinists who were running machines, and which resulted in a great increase in their output.

44 (M) In 1886, the demonstration that the thickness of the chip or layer of metal removed by the tool has a much greater effect upon the cutting speed than any other element, and the practical use of this knowledge in making and putting into everyday use in our shops a series of broad-nosed cutting tools which enabled us to run with a coarse feed at as high a speed as had been before attained with round-nosed tools when using a fine feed, thus substituting, for a considerable portion of the work, COARSE FEEDS AND HIGH SPEEDS for our old maxim of COARSE FEEDS AND SLOW SPEEDS.

45 (N) In 1894 and 1895, the discovery that a greater proportional gain could be made in cutting soft metals through the use of tools made from self-hardening steels than in cutting hard metals, the gain made by the use of self-hardening tools over tempered tools in cutting soft cast iron being almost 90 per cent, whereas the gain in cutting hard steels or hard cast iron was only about 45 per cent. Up to this

time, the use of Mushet and other self-hardening tools had been almost exclusively confined to cutting hard metals, a few tools made of Mushet steel being kept on hand in every shop for special use on hard castings or forgings which could not be cut by the tempered tools. This experiment resulted in substituting self-hardening tools for tempered tools for all "roughing work" throughout the machine shop.

46 (P) In 1894 and 1895, the discovery that in cutting wrought iron or steel a heavy stream of water thrown upon the shaving at the nose of the tool produced a gain in the cutting speed of SELF-HARDENING TOOLS of about 33 per cent. Up to this time the makers of self-hardening steel had warned users never to use water on the tools.

47 (Q) From 1898 to 1900, the discovery and development of the Taylor-White process of treating tools; namely, the discovery that tools made from chromium-tungsten steels when heated to the melting point would do from two to four times as much work as other tools. This is the discovery of modern high-speed tools.

48 (R) In 1899-1902, the development of our slide rules, which are so simple that they enable an ordinary workman to make practical and rapid everyday use in the shop of all the laws and formulæ deduced from our experiments.

49 (S) In 1906, the discovery that a heavy stream of water poured directly upon the chip at the point where it is being removed from CAST IRON by the tool would permit an increase in cutting speed, and therefore, in the amount of work done, of 16 per cent.

50 (T) In 1906, the discovery that by adding a small quantity of vanadium to tool steel to be used for making modern high speed chromium-tungsten tools heated to near the melting point, the red hardness and endurance of tools, as well as their cutting speeds, are materially improved.

51 While many of the results of these experiments are both interesting and valuable, we regard as of by far the greatest value that portion of our experiments and of our mathematical work which has resulted in the development of the slide rules; *i. e.*, the patient investigation and mathematical expression of the exact effect upon the cutting speed of such elements as the shape of the cutting edge of the tool, the thickness of the shaving, the depth of the cut, the quality of the metal being cut and the duration of the cut, etc. This work enables us to fix a daily task with a definite time allowance for each workman who is running a machine tool, and to pay the men a bonus for rapid work.

52 The gain from these slide rules is far greater than that of all the other improvements combined, because it accomplishes the original object, for which in 1880 the experiments were started; *i. e.*, that of

taking the control of the machine shop out of the hands of the many workmen, and placing it completely in the hands of the management, thus superseding "rule of thumb" by scientific control.

53 By far the most difficult and illusive portion of this work has been the mathematical side: first, finding simple formulæ which expressed with approximate accuracy the effect of each of the numerous variables upon the cutting speed; and, second, finding a rapid method of using these formulæ in the solution of the daily machine shop problems. Several times during the progress of this mathematical work, the writer, feeling himself completely baffled, has asked the expert assistance of some of the best mathematicians in the country. They all smiled when told that we expected to solve mathematically a problem containing *twelve variables*, and in each case, after keeping the formulæ before them for a longer or shorter time, returned the problem to the writer with the statement that it belonged distinctly in the realm of "rule of thumb" or empiricism, and could be solved only by the slow method of trial and error.

54 In the investigation of an art such as that of cutting metals, and about which at the time our work was started there was so little scientific knowledge, two types of experiments are possible.

55 First, the thoroughly scientific type, in which, after an analysis of all the variable elements which affect the final result, an attempt is made to hold all of the elements constant and uniform, except the one variable which is under investigation, and this one is systematically changed and its effect upon the problem carefully noted.

56 It is to this type that our experiments belong, thanks mainly to the fact that Mr. William Sellers (one of the most scientific experimenters of his day) was president of the Midvale Steel Company when the writer started his work.

57 Second, the type of experiments in which the effect of two or more variables upon the problem is investigated at the same time and in the same experiment.

58 This method is of course much quicker than the thoroughly scientific type, and it is largely for this reason, in the opinion of the writer, that almost all of the other experimenters in this field have chosen it. Several of the experiments of this type have proved most valuable and developed much useful information, and it is with hesitancy that the writer criticises the work of any of these experimenters, since he appreciates most keenly the difficulties under which they worked, and is grateful for the information contributed by them to the art. After much consideration, however, he has decided to point out what he believes to be a few errors made by these experi-

menters, with the same object which he has in indicating our own false steps: namely, that of warning future investigators against similar errors.

59 Almost the whole course of our experiments is marked by imperfections in our methods, which, as we have realized them, have led us to go again more carefully over the ground previously traveled. These errors may be divided into three principal classes:

60 (A) The adoption of wrong or inadequate standards for measuring the effect of each of the variables upon the cutting speed.

61 (B) Failure on our part from various causes to hold all of the variables constant except the one which was being systematically changed in order to study the effect of these changes upon the cutting speed.

62 (C) The omission either through oversight or carelessness on our part of some one of the precautions which should be taken to insure accuracy, or failure to record some of the phenomena considered unimportant at the time, but which afterward proved to be essential to a complete understanding of the facts.

63 In the second portion of this paper will be given in detail a statement of the appliances, methods and principles which we believe to be necessary to use in order to obtain reliable results. For the purpose of a more general discussion of the subject, however, it seems important to anticipate this portion of the paper by describing in detail the standard which we have finally adopted as a true criterion for determining the effect of each of the variables upon the cutting speed.

64 The effect of each variable upon the problem is best determined by finding the exact rate of cutting speed (say, in feet per minute) which shall cause the tool to be completely ruined after having been run for 20 minutes under uniform conditions.

65 For example, if we wish to investigate the effect which a change in the thickness of the feed has upon the cutting speed, it is necessary to make a number of tools which are in all respects uniform, as to the exact shape of their cutting edge, their clearance and lip angles, their chemical composition and their heat treatment. These tools must then be run one after another, each for a period of 20 minutes, throughout which time the cutting speed is maintained exactly uniform. Each tool should be run at a little faster cutting speed than its predecessor, until that cutting speed has been found which will cause the tool to be completely ruined at the end of 20 minutes (with an allowance of a minute or two each side of the 20-minute mark). In this way that cutting speed is found which corresponds to the particular thickness of shaving which is under investigation.

66 A change is then made in the thickness of the shaving, and another set of 20-minute runs is made, with a series of similar uniform tools, until the cutting speed corresponding to the new thickness of feed has been determined; and by continuing in this way all of the cutting speeds are found which correspond to the various changes of feed. In the meantime, every precaution must be taken to maintain uniform all the other elements or variables which affect the cutting speed, such as the depth of the cut and the quality of the metal being cut; and the rate of the cutting speed must be frequently tested during each 20-minute run to be sure that it is uniform.

67 The cutting speeds corresponding to varying feeds are then plotted as points upon a curve, and a mathematical expression is found which represents the law of the effect of feed upon cutting speed. We believe that this standard or method of procedure constitutes the very foundation of successful investigation in this art; and it is from this standpoint that we propose to criticise both our own experiments and those made by other investigators. For further discussion of our standard method of making experiments see Par. 137.

68 It was only after about 14 years' work that we found that the best measure for the value of a tool lay in the exact cutting speed at which it was completely ruined at the end of 20 minutes. In the meantime, we had made one set of experiments after another as we successively found the errors due to our earlier standards, and realized and remedied the defects in our apparatus and methods; and we have now arrived at the interesting though rather humiliating conclusion that with our present knowledge of methods and apparatus, it would be entirely practicable to obtain through four or five years of experimenting all of the information which we have spent 26 years in getting.

69 The following are some of the more important errors made by us:

70 We wasted much time by testing tools for a shorter cutting period than 20 minutes, and then having found that tools which were apparently uniform in all respects gave most erratic results (particularly in cutting steel) when run for a shorter period than 20 minutes; we erred in the other direction by running our tools for periods of 30 or 40 minutes each, and in this way used up in each single experiment so much of the forging that it was impossible to make enough experiments in cutting metal of uniform quality to get conclusive results. We finally settled on a run of 20 minutes as being the best all-round criterion, and have seen no reason for modifying this conclusion up to date.

71 We next thought a proper criterion for judging the effect of a

given element upon the cutting speed lay in determining the particular cutting speed which would just cause a tool to be slightly discolored below the cutting edge at the end of the 20 minutes. After wasting six months in experimenting with this as our standard, we found that it was not a true measure; and then adopted as a criterion a certain definite dulling or rubbing away of the cutting edge. Later it was found, however, that each thickness of feed had corresponding to it a certain degree of dullness or injury to the cutting edge at which point regrinding was necessary (the thicker the shaving the duller the tool should be before grinding); and a third series of experiments was made with this as a standard. While experimenting on light forgings a standard dullness of tool was used which was just sufficient to push the forging and tool apart and so slightly alter the diameter of the work. All of these criterions were discarded, however, when in 1894 we finally hit upon the true standard, above described, of completely ruining the tool in 20 minutes.

72 As will be pointed out later in the paper, this standard demands both a very large and expensive machine to experiment with, and also large, heavy masses of metal to work upon, which is unfortunate; but we believe without apparatus and methods of this kind it is out of the question to accurately determine the laws which are sought. See paragraphs 210-263.

73 Experiments upon the art of cutting metals (at least those experiments which have been recorded) have been mainly undertaken by scientific men, mostly by professors. It is but natural that the scientific man should lean toward experiments which require the use of apparatus and that type of scientific observation which is beyond the scope of the ordinary mechanic, or even of engineers unless they have been especially trained in this kind of observation. It is perhaps for this reason more than any other that in this art several of those elements which are of the greatest importance have received no attention from experimenters, while far less fruitful although more complicated elements, have been the subject of extended experiments.

74 As an illustration of this fact we would call attention to two of the most simple of all of the elements which have been left entirely untouched by all experimenters, namely:

a the effect of cooling the tool through pouring a heavy stream of water upon it, which results in a gain of 40 per cent in cutting speed;

b the effect of the contour or outline of the cutting edge of the tool upon the cutting speed, which when properly designed results in an equally large percentage of gain.

75 Both of these elements can be investigated at comparatively small cost, and with comparatively simple apparatus, while that element which has received chief attention from experimenters, namely, the pressure of the chip on the tool, calls for elaborate and expensive apparatus and is almost barren of useful results.

76 This should be a warning to all men proposing to make experiments in any field, first, to look thoroughly over the whole field, and, at least, carefully consider all of the elements from which any practical results may be expected; and then to select the more simple and elementary of these and properly investigate them before engaging in the more complicated work.

77 The most notable experiments in this art that have come to the writer's attention are those made at Manchester, England, during the years 1902 and 1903. All these experiments were made jointly by eight of the most prominent English manufacturing companies, among whom were Armstrong, Whitworth & Co.; Vickers' Sons & Maxim, John Brown & Co., Thomas Firth & Sons, and others, who combined with the Manchester Association of Engineers and the Manchester Municipal School of Technology, the latter being principally represented by Dr. J. T. Nicolson, who made the final report entitled "Report on Experiments with Rapid Cutting Steel Tools," for sale by Mr. Frank Hazelton, Secretary, 29 Brown St., Manchester, England.

78 In 1901, a committee of the Verein Deutscher Ingenieure (Union of German Engineers), together with the managers of some of the larger engineering works in Berlin, made an interesting series of experiments which was published September 28, 1901, in the "Zeitschrift des Verein Deutscher Ingenieure," and in November 15, 1905, there were published in Bulletin No. 2 of the University of Illinois, experiments made by Prof. L. P. Breckinridge and Henry B. Dirks.

79 The work of all these men belongs to the second type of experiments above referred to, in which the joint effect of two or more variables is studied at the same time. In the case of the Manchester experiments, the work appears to have been, to a considerable extent, a test as to the all-round knowledge in the art of cutting metals possessed by eight of the prominent English firms. These firms each presented tools made from their own tool steel, treated their own way, and ground to whatever shapes and angles the particular company considered would do the largest amount of work. Each company was allowed to have one guess on each of the qualities of metal worked upon, with each change of feed and depth of cut, as to the cutting speed at which they believed their tool would do the most work. If, under this cutting speed, the tool failed to hold out

throughout the stipulated period of time, they were then given no opportunity to find the exact cutting speed at which the tool would do its best work. And, on the other hand, in those cases in which a tool did good work throughout its specified period of time, no effort was made to find how much faster it could have run and still do good work.

80 A glance at Plates 13, 14 and 15 at the end of Dr. Nicolson's report shows the great variety in the shapes of the tools used in the experiments. Yet no effort was made to definitely determine which make of tool steel or which shape of the tool was best, or even in case a tool did exceptionally good work, no effort was made to determine whether this was due to the shape of the tool or to the quality and treatment of the tool steel.

81 As was to be expected from any such test, each one of the eight companies repeatedly made guesses as to the proper speeds for their tools to run which were very wide of the mark. Yet in spite of this, it is notable that in each case some one of the eight firms guessed fairly close to the proper cutting speed, so that by selecting the best of these various guesses Dr. Nicolson, in writing the report, gives a very valuable and interesting table on p. 250 of the Manchester Report, summarizing the best speeds attained in cutting the soft, medium and hard steels, and the soft, medium and hard cast irons experimented on, in each case with four combined changes of depth of cut and thickness of feed.

82 This table conclusively proves the practical value of experiments of this nature, even when carried on in a thoroughly unscientific manner. There is, however, one element in these experiments which was very carefully investigated, and the results of which are of general scientific value; namely, the determination of the pressure of the chip or shaving upon the nose of the tool.

83 That the conclusions reached as to pressure are of value is due to the fact that upon this particular element, neither the shape of the tool nor the composition or treatment of the tool has very great effect, and in each case the pressure of the chip upon the tool appears to have been carefully observed and tabulated, so that experiments which are valueless from a scientific standpoint for most of the elements, confirm substantially, as to the pressure of the chip on the tool, the results of some of our previous experiments on this element.

84 The writer has a great respect for Dr. Nicolson as an experimenter, as his later work in this field has shown him to be a thoroughly scientific investigator; but feels it necessary to call attention to an error which even he has fallen into, namely, that of attempting to

deduce a formula for the cutting of metals from a summary of the Manchester and German experiments. These experiments, from a scientific standpoint, were so defective as to make it out of the question to deduce formulæ, because no effort was made to keep the following variables uniform: (1) the shape of the cutting edge and the lip and clearance angles of the tool varied from one experiment to another; (2) the quality of the tool steel varied; (3) the treatment of the tool varied; (4) the depth of the cut varied from that aimed at; (5) the cutting speed was not accurately determined at which each tool would do its maximum work throughout a given period of time; and (6) in reading the report of these experiments it does not appear that any careful tests were made to determine whether each of the various forgings and castings experimented on was sufficiently uniform throughout in quality to render the tests made upon them of scientific value. The same criticism, broadly speaking, applies to both the German and the University of Illinois experiments.

85 In fact, in none of these sets of experiments have they appreciated the necessity of MEASURING SEPARATELY the effect produced upon the cutting speed of two of the most important elements in the problem, (*a*) the thickness of the feed, and (*b*) the depth of the cut. In all of these investigations and in formulæ given by Dr. Nicolson on p. 249 of the Manchester report, as well as in a formula published by him in "Technics," for January, 1904, summarizing the results of the Manchester and German experiments, the area of the cut "a" is used as though it were a single variable, whereas the sectional area of the shaving is, in fact, the product of the depth of the cut multiplied by the feed. The fact is, however, that the thickness of the shaving or the feed has a greater effect upon the cutting speed than any other element, while the depth of the cut has only a comparatively small effect. When this is realized, it becomes apparent that any formula or even any data containing the area of the cut (or shaving) as a single element is valueless from a scientific standpoint. To illustrate: a cut which is $\frac{1}{2}$ inch deep with $\frac{1}{32}$ inch feed has the same sectional area as a $\frac{1}{8}$ inch depth cut by $\frac{1}{8}$ inch feed; namely, $\frac{1}{64}$ inch sectional area. Our experiments show that if a cutting speed for a $\frac{1}{8}$ inch by $\frac{1}{8}$ inch cut were 10 feet per minute, then the cutting speed for a $\frac{1}{2}$ inch by $\frac{1}{32}$ inch cut would be 18 feet per minute. From which the impossibility of using the area of the cut as an element in a formula is apparent.

86 Broadly speaking, it is unwise to draw conclusions and make formulæ from experiments in which more than one variable is allowed to vary in the same trial. This criticism is made in no sense to

belittle the value of the work done by others, but with the object to pointedly call the attention of future experimenters to such errors as have been made primarily by ourselves and also by others.

87 The results obtained by Dr. Nicolson from the Manchester experiments led him to make another set of experiments for the purpose of determining accurately the pressure of the chip or shaving upon the cutting edge of the tool. In carrying out this work Dr. Nicolson has designed and constructed what appears to be by far the most scientific apparatus which has yet been made for this purpose. In his paper (published in Transactions, Vol. 25), he has very fully illustrated the apparatus with which he weighs separately the pressure of the chip upon the tool in three directions:

a the VERTICAL PRESSURE;

b the outward pressure or the pressure horizontally at right angles to the axis of the piece being turned; called by him SURFACING PRESSURE;

c the feeding pressure or the pressure horizontally parallel to the axis of the piece being turned; called by him TRAVERSING PRESSURE.

88 His determination of that lip angle of the tool which cuts the metal with the least pressure was of great interest; but, in the writer's judgment, by far the most important and original fact developed by him was brought out by a series of experiments in which he determined the wave-like increase and decrease of the pressure upon the nose of the tool which occurs in cutting metals.

89 In these experiments the chip was removed at a cutting speed of about one foot in five hours. It is notable that no other apparatus heretofore designed was sufficiently scientific and accurate to demonstrate this fact.

90 The writer has taken the liberty of reproducing on Folder 12, Figs. 82 and 86, Dr. Nicolson's diagram, showing this variation in pressure. His discovery is most important in explaining one of the causes for the chattering of tools, and becomes a thoroughly scientific aid in selecting the shape or contour of the cutting edge for standard tools to be used in "roughing work."

91 These experiments form a substantial and permanent addition to our knowledge of the art of cutting metals; and the writer regrets that Dr. Nicolson has not since then investigated other elements immediately affecting the more vital problem of the cutting speed in a similarly thorough manner; since he chose for investigation that element which on the whole is least fruitful in its practical results upon the art of cutting metals, namely, the pressure of the chip upon the tool.

92 However, in choosing this element for investigation Dr. Nicolson made the same error (if such it may be called) into which a most every experimenter in this field fal s sooner or later. From all theoretical standpoints it appears to the novice that a thorough investigation of the effect of the pressure of the chip upon the tool under varying conditions must furnish the key to the whole problem of the variation of cutting speed due to varying feeds, depths of cut, shape of the tool, etc. The fact is, however, that every one who exploits this field finds out sooner or later that there is no traceable relation whatever between the pressure of the chip on the tool and the cutting speed, and but little connection even between the hardness of the metal and the pressure upon the tool. The following is the reasoning which has led us all, at one time or another, into the same error:

93 The ultimate cause for a tool giving out when cutting metal is the dullness or wear of the tool produced by the rubbing or pressure of the chip upon the lip surface of the tool, and the chief element causing this wear, particularly at the high speeds at which tools should be run to do their best work, is the softening of the tool due to the heat produced by the friction of the chip upon its lip surface. Now, it seems perfectly evident that this heat[1] will be increased directly in proportion to three elements:

a the pounds of pressure of the chip upon the tool;

b the speed with which the chip slides across the nose of the tool;

c the coefficient of friction between the chip and the surface of the tool.

And yet, paradoxical as it may seem, the writer again repeats that there is no traceable relation between the pressure of the chip upon the tool and the cutting speed. (The reasons in detail for this will be found later in paragraphs 503 to 519.)

94 So convincing, however, is the above theory that each successive experimenter who has joined the writer in his work has been thoroughly convinced that, through some error in our early experiments upon the pressure of the chip on the tool, we failed to establish the relation between the pressure and the cutting speed which would be demonstrated by a more carefully tried set of experiments; and the writer thinks it is not an exaggeration to state that each of these men in succession remained unconvinced until he had had the opportunity of verifying this fact for himself.

[1] Dr. Nicolson, in his criticism of this paper, calls attention to the fact that more heat is generated in bending the chip or causing the molecules of the metal of the chip to flow past one another, than through the pressure of the chip on the tool.

95 As an illustration of the mental effect of this theory upon these experimenters: In one case, a bright and thoroughly honest young man, who was employed by the writer to help on the mathematical side of this work, became so thoroughly convinced through the above reasoning that the main lines on which we were carrying on our investigation would be rendered entirely unnecessary by a series of pressure tests made by himself, that upon being told by the writer that he would not allow the expense to be incurred for another series of pressure tests, he wrote a memorial of many pages to the Board of Directors of the company in which the experiments were being carried on, explaining his own thorough scientific attainments and the writer's lack of the same, and that, therefore, our relative positions ought to be reversed, that he should do the directing and the writer shou d do the work. And, finally, when his protests were not heeded, he resigned his position; and the writer has been told that he subsequently induced another company to allow him to experiment on his own account. However, up to date there has not appeared any published record of these experiments.

96 We are dwelling at such length upon this element in the art because it has constituted the pit into which so many experimenters have fallen; and upon failing to trace any scientific relation between the pressure and the cutting speed they are very apt to conclude that the whole subject of cutting metals belongs to the domain of "rule of thumb" rather than to that of exact science, and give up further work in this field.

97 It may almost be said that investigations heretofore made upon the general subject of the pressure of the chip upon the tool have proved barren of useful and practical results, except in so far as they have furnished the knowledge needed by tool builders for giving their machines the proper driving power. It is with little hesitation that the writer makes the assertion that if no experiments whatever had been made in this field, the knowledge of the art of cutting metals would be on the whole in a more advanced state than it is now, since experimenters in all countries instead of studying pressures would have given their attention to some one of the other lines of investigation which bear directly and yield valuable information upon the one most important subject of cutting speed.

98 It is a noteworthy fact that when thorough investigations are attempted by earnest men in new fields, while frequently the object aimed at is not attained, yet quite often discoveries are made which are entirely foreign to the purpose for which the investigation was undertaken. And it may be said that the indirect results of careful

scientific work are, generally speaking, fully as valuable as the direct. Two interesting illustrations of this fact have been furnished by our experiments.

99 The discovery of the Taylor-White process of treating tools by heating them almost to the melting point, or, in other words, the intoduction of modern high speed tools the world over, was the indirect result of one of our lines of investigation.

100 The demonstration of the fact that the rules for using belting in common practice furnished belts which were entirely too light for economy was also one of the indirect results of our experiments.

101 The manner of making these discoveries was each time in a way so typical of what may be expected in similar cases that it would seem worth while to describe it in some detail.

102 During the winter of 1894–1895, the writer conducted an investigation in the shop of Wm. Sellers & Co., at the joint expense of Messrs. William Cramp & Sons, shipbuilders, and Messrs. Wm. Sellers & Co., to determine which make of self-hardening tool steel was, on the whole, the best to adopt as standard for all of the roughing tools of these two shops.

103 As a result of this work, the choice was narrowed down at that time to two makes of tool steel: (1) the celebrated Mushet self-hardening steel, the chemical composition of the particular bar analyzed at this time being as follows:

TUNGSTEN PER CENT	CHROMIUM PER CENT	CARBON PER CENT	MANGANESE PER CENT	SILICON PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT
5.441	0.398	2.150	1.578	1.044		

and (2) a self-hardening steel made by the Midvale Steel Company of the following chemical composition:

TUNGSTEN PER CENT	CHROMIUM PER CENT	CARBON PER CENT	MANGANESE PER CENT	SILICON PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT
7.723	1.830	1.143	0.180	0.246	0.023	0.008

104 Of these two steels, the tools made from the Midvale steel were shown to be capable of running at rather higher cutting speeds. The writer himself heated hundreds of tools of these makes in the course

of his experiments in order to accurately determine the best temperatures for forging and heating them prior to grinding so as to get the best cutting speeds. In these experiments he found that the Mushet steel if overheated crumbled badly when struck even a light blow on the anvil, while the Midvale steel if overheated showed no tendency to crumble, but, on the other hand, was apparently permanently injured. In fact, heating these tools slightly beyond a bright cherry red caused them to permanently fall down in their cutting speeds; and the writer was unable at that time to find any subsequent heat treatment which would restore a tool broken down in this way to its original good condition. This defect in the Midvale tools left us in doubt as to whether the Mushet or the Midvale was, on the whole, the better to adopt as a shop standard.

105 In the summer of 1898, soon after undertaking the reorganization of the management of the Bethlehem Steel Company, the writer decided to continue the experiments just referred to with a view to ascertaining whether in the meanwhile some better tool steel had not been developed. After testing several additional makes of tools, our experiments indicated that the Midvale self-hardening tools could be run if properly heated at slightly higher speeds than those of any other make.

106 Upon deciding to adopt this steel as our standard the writer had a number of tools of each make of steel carefully dressed and ground to exactly the same shape. He then called the foremen and superintendents of the machine shops of the Bethlehem Steel Company to the experimental lathe so that they could be convinced by seeing an actual trial of all of the tools that the Midvale steel was, on the whole, the best. In this test, however, the Midvale tools proved to be worse than those of any other make; *i. e.*, they ran at slower cutting speeds. This result was rather humiliating to us as experimenters who had spent several weeks in the investigation.

107 It was of course the first impression of the writer that these tools had been overheated in the smith shop. Upon careful inquiry among the smiths, however, it seemed as though they had taken special pains to dress them at a low heat, although the matter was left in much doubt. The writer, therefore, determined to make a thorough investigation before finally adopting the Midvale steel as our shop standard to discover if possible some heat treatment which would restore Midvale tools injured in their heating (whether they had been underheated or overheated) to their original good condition.

108 For this purpose Mr. White and the writer started a carefully

laid out series of experiments, in which tools were to be heated at temperatures increasing, say, by about 50 degrees all the way from a black heat to the melting point. These tools were then to be ground and run in the experimental lathe upon a uniform forging, so as to find:

a that heat at which the highest cutting speed could be attained (which our previous experiments had shown to be a cherry red);

b to accurately determine the exact danger point at which if over or underheated these tools were seriously injured;

c to find some heat treatment by which injured tools could be restored to their former high cutting speeds.

109 These experiments corroborated our Cramp-Sellers experiments, showing that the tools were seriously broken down or injured by overheating, say, somewhere between 1550 degrees F. and 1700 degrees F.; but to our great surprise, tools heated up to or above the high heat of 1725 degrees F. proved better than any of those heated to the best previous temperature, namely, a bright cherry red; and from 1725° F. up to the incipient point of fusion of the tools, the higher they were heated, the higher the cutting speeds at which they would run.

110 Thus, the discovery that phenomenal results could be obtained by heating tools close to the melting point, which was so completely revolutionary and directly the opposite of all previous heat treatment of tools, was the indirect result of an accurate scientific effort to investigate as to which brand of tool steel was, on the whole, the best to adopt as a shop standard; neither Mr. White nor the writer having the slightest idea that overheating beyond the bright cherry red would do anything except injure the tool more and more the higher it was heated.

111 During our early Midvale Steel Company experiments, extending from 1880 to 1883, the writer had so much trouble in maintaining the tension of the belt used in driving the boring mill upon which he was experimenting that he concluded: (1) that belting rules in common use furnished belts entirely too light for economy; and (2) that the proper way to take care of belting was to have each belt in a shop tightened at regular intervals with belt clamps especially fitted with spring balances, with which the tension of the belt was accurately weighed every time it was tightened, each belt being retightened each time to exactly the same tension.

112 In 1884, the writer designed and superintended the erection of a new machine shop for the Midvale Steel Company, and this gave

him the opportunity to put these conclusions to a practical test. About half the belts in the shop were designed according to the ordinary rules and the other half were made about two and one-half times as heavy as the usual standard. This shop ran day and night. The belts were in all cases cared for and retightened only upon written orders sent from the shop office; and an accurate record was kept through nine years of all items of interest concerning each belt, namely: the number of hours lost through interruption to manufacture; the number of times each belt interrupted manufacture; the orginal cost of each belt; the detail costs of tightening, cleaning and repairing each belt; the fall in the tension before requiring retightening; and the time each belt would run without being retightened. Thus at the end of nine years these belts furnished a record which demonstrated beyond question many important facts connected with the use of belting, the principal of these being that the ordinary rules gave belts only about one-half as heavy as should be used for economy.[1] This belting experiment illustrates again the good that often comes indirectly from experiments undertaken in an entirely different field.

113 After many years of close personal contact with our mechanics, I have great confidence in their good judgment and common sense in the long run, and I am proud to number many of them among my most intimate friends.

114 As a class, however, they are extremely conservative, and if left to themselves their progress from the older toward better methods will be exceedingly slow. And my experience is that rapid improvement can only be brought about through constant and heavy pressure from those who are over them.

115 It must be said, therefore, that to get any great benefit from the laws derived from these experiments, our slide rules must be used, and these slide rules will be of but little, if any, value under the old style of management, in which the machinist is left with the final decision as to what shape of tool, depth of cut, speed, and feed, he will use.

116 The slide rules cannot be left at the lathe to be banged about by the machinist. They must be used by a man with reasonably clean

[1] The writer presented a paper to this Society in 1893 (published in Transactions, Vol. 15) upon this series of experiments. He has since found, however, that in the minds of many readers the value of the conclusions arrived at have been seriously brought into question largely through the criticism of one man, which at the time appeared to the writer so ridiculous that he made the mistake of thinking it not worth answering in detail. This should be a warning to writers to answer carefully all criticism, however foolish.

hands, and at a table or desk, and this man must write his instructions as to speed, feed, depth of cut, etc., and send them to the machinist well in advance of the time that the work is to be done. Even if these written nstructions are sent to the machinist, however, little attention will be paid to them unless rigid standards have been not only adopted, but ENFORCED, throughout the shop for every detail, large and small, of the shop equipment, as well as for all shop methods. And, further, but little can be accomplished with these laws unless the old style foreman and shop superintendent have been done away with, and functional foremanship has been substituted,—consisting of speed bosses, gang bosses, order-of-work men, inspector, time study men, etc. In fact, the correct use of slide rules involves the substitution of our whole task system of management for the old style management, as described in our paper on "Shop Management" (Transactions, Vol. 24). This involves such radical, one might almost say, revolutionary, changes in the mental attitude and habits both of the workmen and of the management, and the danger from strikes[1] is so great and the chances for failure are so many, that such a reorganization should only be undertaken under the direct control (not advice but CONTROL) of men who have had years of experience and training in introducing this system.

117 A long time will be required in any shop to bring about this radically new order of things; but in the end the gain is so great that I say without hesitation that there is hardly a machine shop in the country whose output cannot be doubled through the use of these methods. And this applies not only to large shops, but also to comparatively small establishments. In a company whose employees all told, including officers and salesmen, number about one hundred and fifty men, we have succeeded in more than doubling the output of the shop, and in converting an annual loss of 20 per cent upon the old volume of business into an annual profit of more than 20 per cent upon the new volume of business, and at the same time rendering a lot of disorganized and dissatisfied workmen contented and hard working, by insuring them an average increase of about 35 per cent in their wages. And I take this opportunity of again saying that those companies are indeed fortunate who can secure the services of

[1]The danger from strikes comes from the false steps often taken by men not familiar with the methods which should be used in introducing the system. The writer has never had a single strike during the 26 years he has been engaged in this work.

men to direct the introduction of this type of management who have had sufficient training and experience to insure success.[1]

118 Unfortunately those fundamental ideas upon which the new task management rests mainly for success are directly antagonistic to the fundamental ideas of the old type of management. To give two out of many examples: Under our system the workman is told minutely just what he is to do and how he is to do it; and any improvement which he makes upon the orders given him is fatal to success. While, with the old style, the workman is expected to constantly improve upon his orders and former methods. Under our system, any improvement, large or small, once decided upon goes into immediate use, and is never allowed to lapse or become obsolete, while under the old system, the innovation unless it meets with the approval of the mechanic (which it never does at the start) is generally for a long time, at least, a positive impediment to success. Thus, many of those elements which are mainly responsible for the success of our system are failures and a positive clog when grafted on to the old system.

119 For this reason the really great gain which will ultimately come from the use of these slide rules will be slow in arriving—mainly, as explained, because of the revolutionary changes needed for their successful use—but it is sure to come in the end.

120 Too much emphasis cannot be laid upon the fact that standardization really means simplification. It is far simpler to have in a standardized shop two makes of tool steel than to have 20 makes of tool steel, as will be found in shops under the old style of management. It is far simpler to have all of the tools in a standardized shop ground by one man to a few simple but rigidly maintained shapes than to have, as is usual in the old style shop, each machinist spend a portion of each day at the grindstone, grinding his tools with radically wrong curves and cutting angles, merely because bad shapes are easier to grind than good. Hundreds of similar illustrations could be given showing the true simplicity (not complication) which accompanies the new type of management.

121 There is, however, one element in which the new type of management to all outward appearance is far more complicated than the old; namely, no standards and no real system of management can be maintained without the supervision and, what is more, the hard work of men who would be called by the old style of management supernumeraries or non-producers. The man who judges of the com-

[1] The writer feels free to give this advice most emphatically without danger of having his motives misinterpreted, since he has himself given up accepting professional engagements in this field.

plication of his organization only by looking over the names of those on the pay-roll and separating the so-called non-producers from the producers, finds the new style of management more complicated than the old.

122 No one doubts for one minute that it is far simpler to run a shop with a boiler, steam engine, shafting, pulleys and belts than it would be to run the same shop with the old fashioned foot power, yet the boiler, steam engine, shafting, pulleys and belts require, as supernumeraries or non-producers on the pay-roll, a fireman, an engineer, an oiler and often a man to look after belts. The old style manager, however, who judges of complication only by comparing the number of non-producers with that of the producers, would find the steam engine merely a complication in management. The same man, to be logical, would find the whole drafting force of an engineering establishment merely a complication, whereas in fact it is a great simplification over the old method.

123 Now our whole system of management is quite accurately typified by the substitution of an elaborate engine to drive and control the shop in place of the old fashioned foot power. There is no question that our human managing machine, which is required for the maintenance and the effective use of both standard shop details, and standard methods throughout the establishment, and for giving each workman each day in advance a definite task which must be finished in a given time, calls for many more non-producers than are used with the old style management having its two or three foremen and a superintendent. The efficiency of our engine of management, however, compared with the old single foreman is like a shop engine as compared with foot power or the drafting room as compared with having the designing done by the pattern maker, blacksmith and machinist.

124 A study of the recommendations made throughout this paper will illustrate the fact that we propose to take all of the important decisions and planning which vitally affect the output of the shop out of the hands of the workmen, and centralize them in a few men, each of whom is especially trained in the art of making those decisions and in seeing that they are carried out, each man having his own particular function in which he is supreme, and not interfering with the functions of other men. In all this let me say again that we are aiming at true simplicity, not complication.

125 There is one recommendation, however, in modern machine shop practice in making which the writer will probably be accused of being old fashioned or ultra-conservative.

126 Of late years there has been what may be almost termed a blind rush on the part of those who have wished to increase the efficiency of their shops toward driving each individual machine with an independent motor. The writer is firmly convinced through large personal observation in many shops and through having himself systematized two electrical works that in perhaps three cases out of four a properly designed belt drive is preferable to the individual motor drive for machine tools. There is no question that through a term of years the total cost, on the one hand, of individual motors and electrical wiring, coupled with the maintenanace and repairs, of this system will far exceed the first cost of properly designed shafting and belting plus their maintenance and repairs (in most shops entirely too light belts and counter shafts of inferior design are used, and the belts are not systematically cared for by one trained man and this involves a heavy cost for maintenance). There is no question, therefore, that in many cases the motor drive means in the end additional complication and expense rather than simplicity and economy.

127 It is at last admitted that there is little, if any, economy in power obtainable through promiscuous motor driving; and it will certainly be found to be a safe rule not to adopt an individual motor for driving any machine tool unless a clearly evident and a large saving can be made by it.

128 In concluding let me say that we are now but on the threshold of the coming era of true coöperation. The time is fast going by for the great personal or individual achievement of any one man standing alone and without the help of those around him. And the time is coming when all great things will be done by the coöperation of many men in which each man performs that function for which he is best suited, each man preserves his own individuality and is supreme in his particular function, and each man at the same time loses none of his originality and proper personal initiative, and yet is controlled by and must work harmoniously with many other men.

129 And let me point out that the most important lessons taught by these experiments, particularly to the younger men, are:

THAT SEVERAL MEN WHEN HEARTILY COÖPERATING, EVEN IF OF EVERYDAY CALIBER, CAN ACCOMPLISH WHAT WOULD BE NEXT TO IMPOSSIBLE FOR ANY ONE MAN EVEN OF EXCEPTIONAL ABILITY.

THAT EXPENSIVE EXPERIMENTS CAN BE SUCCESSFULLY CARRIED ON BY MEN WITHOUT MONEY, AND THE MOST DIFFICULT MATHEMATICAL PROBLEMS CAN BE SOLVED BY VERY ORDINARY MATHEMATICIANS; PROVIDING ONLY THAT THEY ARE

WILLING TO PAY THE PRICE IN TIME, PATIENCE AND HARD WORK.

THAT THE OLD ADAGE IS AGAIN MADE GOOD THAT "ALL THINGS COME TO HIM WHO WAITS," IF ONLY HE WORKS HARD ENOUGH IN THE MEANTIME.

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ON THE ART OF CUTTING METALS

PART 2[a]

DIVISION—DETAILS OF EXPERIMENTS—LAWS DEDUCED—PRACTICAL APPLICATION OF LAWS

130 There are three principal objects in writing this section of the paper.

131 (A) To record and make public the results of our experiments to date as embodied in laws, etc., and the incorporation of these laws in slide rules for practical, everyday use.

132 (B) To describe the methods, principles and apparatus which should be used in making investigations of this type, and warn future experimenters against the errors into which we, as well as most other investigators in this field, have fallen.

133 (C) To indicate the additional experiments which are needed to perfect our knowledge of the art, in the hope of inducing others to join us in carrying on and completing this work, both in the interest of science and of the many users of machine tools the world over; and to warn others against a certain class of experiments which are alluring, appear to offer great opportunities, but which, in fact, are fruitless.

134 The writer wishes to emphasize the fact that, while many of our experiments have a certain scientific value, and while it has been our effort to conduct all of our work upon scientific principles, yet the main object of this investigation has been the thoroughly practical one of enabling us to get more, better and cheaper work out of a machine shop.

135 The problem before us may be again briefly stated to consist of a careful study of the effect which each of the twelve following variable elements has upon the selection of the CUTTING SPEED OF THE TOOL:

[a] The subjects treated in this section of the paper are from their nature so dependent one upon another, and so interwoven, that the writer has had difficulty in treating them consecutively and logically. He therefore trusts that a certain amount of repetition and the necessity for referring frequently from one part of the paper to another will be pardoned.

a The quality of the metal which is to be cut, *i. e.*, its hardness or other qualities which affect the cutting speed;

b The diameter of the work;

c The depth of the cut, or one-half of the amount by which the forging or casting is being reduced in diameter in turning;

d The thickness of the shaving, or the thickness of the spiral strip or band of metal which is to be removed by the tool, measured while the metal retains its original density; not the thickness of the actual shaving, the metal of which has become partly disintegrated;

e The elasticity of the work and of the tool;

f The shape or contour of the cutting edge of the tool, together with its clearance and lip angles;

g The chemical composition of the steel from which the tool is made, and the heat treatment of the tool;

h Whether a heavy stream of water, or other cooling medium, is used on the tool;

j The duration of the cut, *i. e.*, the time which a tool must last under pressure of the shaving without being reground;

k The pressure of the chip or shaving upon the tool;

l The changes of speed and feed possible in the lathe;

m The pulling and feeding power of the lathe at its various speeds.

136 It is of course superfluous to call the attention of those who have given much thought to the subject of cutting metals as an art, to the fact that the ultimate object of all experiments in this field is to learn how to remove the metal from our forgings and castings in the quickest time, and that therefore the art of cutting metals may be briefly defined as the knowledge of how, with the limitations caused by some and the opportunities offered by others of the above twelve variable elements, in each case to remove the metal with the highest appropriate cutting speed. And yet a walk through almost any machine shop will convince anyone that if those in charge of the shop are aware of the effect of speed upon economy, they are acting upon this information only in a few sporadic cases and by no means systematically.

137 Before entering upon the details of our experiments, it seems necessary to again particularly call attention to the fact that "standard cutting-speed" is the true criterion by which to measure the

effect of each of these twelve variables upon the problem. The writer therefore repeats what he has before said in paragraph 64 (Part 1):

"THE EFFECT OF EACH VARIABLE UPON THE PROBLEM IS BEST DETERMINED BY FINDING THE EXACT RATE OF CUTTING SPEED (SAY, IN FEET PER MINUTE) WHICH WILL CAUSE THE TOOL TO BE COMPLETLY RUINED AFTER HAVING BEEN RUN FOR 20 MINUTES UNDER UNIFORM CONDITIONS."

138 To give another illustration of our practical use of this standard. If, for example, we wish to determine which make of tool steel is the best, we should proceed to make from each of the two kinds to be tested a set of from four to eight tools. Each tool should be forged from tool steel, say, $\frac{1}{4}$ inch x $1\frac{1}{4}$ inch and about 18 inches long, to exactly the same shape, and after giving the tools made from each type of steel the heat treatment appropriate to its chemical composition, they should all be ground with exactly the same shaped cutting edge and the same clearance and lip angles. One of the sets of eight tools should then be run, one tool after another, each for a period of 20 minutes, and each at a little faster cutting speed than its predecessor, until that cutting speed has been found which will cause the tool to be completely ruined[1] at the end of 20 minutes, with an allowance of a minute or two each side of the 20-minute mark.

139 Every precaution must be taken throughout these tests to maintain uniform all of the other elements or variables which affect the cutting speed, such as the depth of the cut and the quality of the metal being cut. The rate of the cutting speed must be frequently tested during each 20-minute run to be sure that it is uniform throughout. For further details in making tests, see paragraphs 175 to 262.

140 Throughout this paper, "the speed at which tools" give out in 20 minutes, as described above, will be, for the sake of brevity, referred to as the "standard speed."

141 After having found the "standard speed" of the first type of tools, and having verified it by ruining several more of the eight tools at the same speed, we should next determine in a similar manner the exact speed at which the other make of tools will be ruined in 20 minutes; and if, for instance, one of these sets of tools exactly ruins at a cutting speed of 55 feet, while the other make ruins at 50 feet per minute, these "standard speeds," 55 to 50, constitute by far the most important criterion from which to judge the relative economic value of the two steels for a machine shop.

[1] For the advantage of completely ruining a tool in experimenting as a standard method see paragraph 151.

142 Other properties of the steels, as mentioned in paragraphs 934 to 1094, must of course be considered in choosing a tool steel. But if the steels are in other respects equal, their maximum cutting speeds then represent the exact measure of their values.

143 Perhaps the best criterion by which to judge of the value of any standard or test is the ability to duplicate the results which have been once obtained. We have repeatedly been able to reduplicate the results obtained through this standard within an error of 2 per cent. For our reasons for adopting the 20 minute period as our standard running time see paragraphs 175 to 184.

"STANDARD SPEED" BEST TEST FOR DETERMINING VALUE OF TOOLS, ETC.

144 It seems necessary early in this paper to emphasize the importance of the "standard speed" as being the true test for the relative value of tools as well as for the other elements involved in the art of cutting metals—the more so since the accuracy and delicacy of this standard are but vaguely recognized.

145 Among those commonly referred to, the most deceptive and unreliable standard as to the relative value of tools is THE LENGTH OF TIME A TOOL WILL RUN BEFORE REQUIRING GRINDING or before being ruined. So many people are continually being misled by this standard that its inadequacy can scarcely be over-emphasized.

146 To illustrate: Let us assume, for instance, that three tools have been proved to be uniform within, say, 2 per cent by our standard method, described in paragraph 138, and to have a "standard speed" of 60 feet per minute for a run of 20 minutes. If then the cutting speed of each of these tools is increased, say, to 63 feet per minute, THE LENGTH OF TIME WHICH THEY WILL RUN at this slight increase in cutting speed will be almost sure to vary greatly. One of the tools will be ruined, say, in six minutes, another in nine minutes, while the third may last 15 minutes. Thus if tools which are uniform within 2 per cent are run only slightly beyond "standard speed," they are likely to vary to the extent of more than 2 to 1 in time which they last before ruining or requiring regrinding; and so the misleading nature of the standard becomes apparent.

147 The great variation in the time which carefully standardized tools will last when run at an increase in cutting speed of only one foot per minute will be seen by examining table in paragraph 619. In this case it will be seen that an increase of only one foot in cutting speed causes standardized tools to vary in their running period, in the two extreme cases, between the periods of 1½ minutes

and 17½ minut... A study of this table will show that the value of the tools is closely given by standard cutting speeds, but that it is in no sense proportional to the time which the tool runs before being ruined. This matter will be further discussed in paragraph 619. etc.

148 The inadequacy of this standard is, however, so little recognised that even as able an experimenter as Dr. Nicolson, after having written the record of the "Manchester Experiments," and then made his own admirable "Dynamometer Experiments," falls into the error of adopting this false standard in his "Experiments on Durability of Different Cutting Angles," described in his paper in Tables 5, 6 and 7, and in paragraphs 38 to 44 inclusive, pp. 657 to 661. Yet in these very experiments the misleading nature of this standard will be seen. Note that in Table 7, for instance, a 75 degree angle tool at a cutting speed of 74 feet per minute lasts only 2 minutes 10 seconds, while the same tool when run only one foot per minute slower at a cutting speed of 73 feet per minute lasts 10 minutes and 37 seconds.

149 For many years it has been usual for salesmen of tool steels to give detailed accounts of the number of hours which tools made from their steels, would cut metals without the necessity of regrinding. In fact, tool steel literature abounds in statements of the long life of tools with one grinding, implying that this is the proper standard for measuring their value. By referring, however, to paragraphs 693 and 710 it will be seen that for ninety-nine one-hundredths of the work of a shop, this criterion is of no value whatever, and that the man who boasts of having run a tool without regrinding, say, for a longer period than one and one-half hours on ordinary shop work, is merely boasting of how little he knows about the art of cutting metals cheaply.

150 The writer has already referred in paragraph 92 (Part 1) to another error into which all experimenters in this art fall sooner or later: namely, that of concluding that the effect which the size, shape and angles of the tool has upon the problem of cutting metals can best be determined by a careful investigation of the effect which each of these elements has upon the pressure required to remove a given sized chip or shaving. The reasoning used is that that tool is the best which is so shaped as to remove a given chip or shaving with the least amount of pressure or cutting force. The utter fallacy of this as a measure of the value of the tool has already been referred to in paragraph 92, and will be again referred to in paragraph 135.

151 In paragraph 59 (Part 1) the writer has described several false standards which were adopted by us, one after another, for determining when a tool had been run at its maximum cutting speed. Even with these defective standards we obtained most useful results. Broadly speaking, however, our reason for successively abandoning each of these standards was the impossibility of accurately reduplicating the results obtained. And this after all remains the best gage of the value of experimental methods. In all cases the earlier standards adopted by us required very close observation and judgment on the part of the experimenter to determine when the tool had reached that state of deterioration which was appropriate to its highest cutting speed. The advantage of our present standard, namely, that of completely ruining the tool, lies in the fact that it is an unmistakable, clear-cut phenomenon which calls for a minimum of judgment on the part of the operator, and thus eliminates one of the sources of human error in the experiments, and enables us to reduplicate our results with accuracy.

152 On Folder 3, Fig. 17b, are shown two views of a tool which has been completely ruined according to this standard.

ACTION OF TOOL AND ITS WEAR IN CUTTING METALS

THE ACTION OF THE NOSE OF THE TOOL

153 On Folder 8, Figs. 42, 43 and 44, is illustrated in enlarged views the action of a tool in cutting a chip or shaving from a forging at its proper normal cutting speed. It may be said in the case of all "roughing cuts" that the chip is torn away from the forging rather than removed by the action which we term cutting. The familiar action of cutting, as exemplified by an axe or knife removing a chip from a piece of wood, for instance, consists in forcing a sharp wedge (*i. e.*, one whose two flanks form an acute angle) into the substance to be cut. Both flanks of the wedge press constantly upon the wood, one flank bearing against the main body of the piece, while the other forces or wedges the chip or shaving away.

154 While a metal cutting tool looks like a wedge, its cutting edge being formed by the intersection of the "lip surface" and "clearance surface" or flank of the tool, its action is far different from that of the wedge. Only one surface of a metal cutting tool, the lip surface, ever presses against the metal. The clearance surface, as its name implies, is never allowed to touch the forging. Thus "cutting" with a metal cutting tool consists in pressing, tearing or shearing the metal

away with the lip surface of the "wedge" only under pressure, while in the case of the axe and other kinds of cutting, both wedge surfaces are constantly under pressure.

155. After the cut has once been started, and the full thickness of the shaving is being removed, the action of the tool may be described as that of tearing the chip away from the body of the forging and then shearing it up into separate sections; the portion of the chip which has just been torn away, and which is still pressing upon the lip surface of the tool, acting as a lever by which the following portion of the chip is torn away from the main body of the metal.

156 It may be of interest to analyze to a certain extent the nature of the forces to which a chip and the forging from which it is being removed are subjected through the tearing action of the tool. The enlarged view of the chip, tool and forging, shown in Folder 8, Fig. 42, represents with fair accuracy the relative proportions which the shaving cut from a forging of mild steel (say, 60,000 lbs. tensile strength and 33% stretch) finally assumes with relation to the original thickness of the layer of metal which the tool is about to remove. It is, of course, impossible to accurately determine the extent to which various parts of the chip and forging close to the tool are under compression and tension, but in general the theory advanced is believed to be correct.

157 Referring to Folder 8, Fig. 42, the forging being cut and the nose of the tool which is removing the chip are shown on an enlarged scale. The thickness of the layer of metal about to be removed is indicated by L between the dotted line and the full line which represents the outside of the forging. It will be observed that the chip is in process of being torn apart and broken up into three sections: Section 1, which is adjoining the forging; section 2, which comes next to it, and in which rupture or cleavage has started and proceeded a little way up from the bottom of the chip and on the left hand side, the shearing action having progressed as far as T_2; section 3, in which shearing has progressed about two-thirds of the way to the top of the chip and is taking place at T_3. Section 4 has been entirely sheared from its adjoining section, and has already left the lip surface of the tool.

158 On examination of the proportions of the chip it will be noticed that the width of the sections into which the chip breaks up is at their base about double the thickness of the original layer of metal which is to be removed, and that their upper portions are not enlarged to the same extent. These sections are about three times as high as the original thickness of the layer of the metal to be removed.

It should be clearly understood that the dimensions of the section of the chip will vary with each hardness of metal which is being cut, and also to a certain extent with the side and back slopes of the lip surface of the tool. The harder the metal of the forging, the less will each section into which the chip has been broken up be found to be enlarged. In other words, if the same shaped tool be used in each case the chip from soft metal enlarges or distorts very much more than the corresponding chip from hard steel. This will be referred to in paragraph 506, in explaining the reason why the total pressure on the tool has but little relation on the one hand to the cutting speed, and on the other hand to the hardness of the metal which is being cut.

159 The chip bears on the surface of the forging, say, from point H to point G, and throughout this distance is under constant compression from the lip surface of the tool. This compression is transmitted through each of the sections 1 and 2 of the chip, in the direction indicated by the small arrows, to the upper portions of these sections, which are still unbroken and act like a lever attached to the upper part of section 1 to tear[1] section 1 away from the body of the forging, as indicated at point T_1. The tearing away of section 1 is also assisted by the pressure of the tool upon its lower surface.

160 After this tearing action has started, the further breaking of the chip into independent sections would seem to be that of simple shearing. It should be borne in mind that in shearing a thick piece of steel the whole piece is not shorn or cut apart at the same instant, but the line at which rupture or cleavage takes place progresses from one surface of the piece down through the metal until within a short distance from the other surface, when the whole remaining section rather suddenly gives way.

161 In shearing steel, the metal at the point of rupture is pulled apart under a tensile strain, although on each side of the shearing line the metal is under heavy compression.

162 As each of the sections of the chip successively comes in contact with the lip of the tool, its lower surface is crushed, and the metal flows and spreads out laterally until it becomes about twice its original thickness. As in all shearing, when the full capacity for flowing of the metal has been reached, it tears apart under tensile strain from the body of the adjoining metal of the forging. The compression on the chip from the tool still continues, however, and the chips continue to

[1]For further evidence that the chip is torn away from the body of the forging somewhat as shown at T_1, see paragraphs 170–174.

flow and spread out sideways at a part higher up; *i. e.*, farther away from the surface of the tool, at the portions marked *F*. In the same way shearing continually takes place at the left side of the portion of the chip which is flowing or spreading out sideways.

163 There is no question that shearing takes place constantly along the left hand edges of two of the sections of the chip at the same time, and it is probable that this action occurs most of the time along three lines of cleavage. See paragraph 167.

164 Dr. Nicolson's dynamometer experiments show that the pressure of the chip on the tool in cutting a chip of uniform section varies with wavelike regularity, and that the smallest pressure of the chip is not less than two-thirds of the greatest pressure. From this it is evident that shearing must be taking place along at least two lines of cleavage at the same time; since if each of the sections into which the chip is divided were completely broken off before the tool began to break off the following section, it is evident that there would be times when there was almost no pressure from the chip on the tool.

165 It is at first difficult to see how it is possible for the chip to be shearing at two or three places at the same time. It should be noted, however, that above the points T_1, T_2, T_3, the metal of the chip is still a solid part of the forging, and moves down at the same speed as the forging in a single mass, or body, toward the lip surface of the tool; and with sufficient force to cause each of the three sections of the chip to flow or spread out at the same time at the parts indicated by the three letters *F*. According to the laws which govern shearing, rupture or cleavage in each case must take place as soon as the maximum possibility for flowing has been reached, and in each case shearing must occur at the left of the zone where the metal is flowing.

166 It is probable that after the shearing action has progressed in section 3 to about the point indicated by T_3, that the whole of this section gives way or shears with a rather sudden yielding of the metal from T_3, to the upper surface of the chip. It is this rather sudden shearing point which undoubtedly causes the wavelike diminution in the pressure of the chip indicated in Dr. Nicolson's experiments, referred to in paragraph 316.

167 By suddenly stopping one of our standard tools when cutting at full speed, we have clearly seen this shearing action taking place at two sections of the chip at the same time, and rupture had not completely taken place at the extreme upper part of the third section. In making an observation of this kind great care must be taken before stopping the lathe to be sure that in the tool to be observed there is not the slightest tendency to chatter, and the lathe driving parts

should be massive in proportion to the sized cut being taken, as otherwise the elasticity left in the driving shafts causes an abnormal action of the tool at the instant the work stops, and produces a chip, of thicker section than the normal, which is completely severed from the body of the metal.

168 While the proportions of the chip and the section into which it is broken are fairly true representations of fact, yet it must be borne in mind that the lines illustrating the strains to which the chips are submitted, as well as the progress made in the shearing of the chip, are merely submitted as illustrating a theory advanced by us to explain the facts. We are, however, more or less suspicious of all theories, our own as well as those of others.

169 Throughout this paper the important facts stated by us have been verified by many and carefully made experiments; and we therefore trust that our readers, if unable to accept our theories, will at least have respect for our facts.

ACTION OF CUTTING EDGE OF TOOL IS THAT OF SCRAPING—CUTTING EDGE NOT UNDER HEAVY PRESSURE

170 It would appear that the chip is torn off from the forging at a point appreciably above the cutting edge of the tool and this tearing action leaves the forging in all cases more or less jagged or irregular at the exact spot where the chip is pulled away from the forging, as shown to the left of T_1. An instant later the line of the cutting edge, or more correctly speaking, the portion of the lip surface immediately adjoining the cutting edge, comes in contact with these slight irregularities left on the forging owing to the tearing action, and shears these lumps off, so as to leave the receding flank of the forging comparatively smooth.

171 Thus in this tearing action, particularly in the case of cutting a thick shaving, while the cutting edge of the tool is continually in action, scraping or shearing off or rubbing away these small irregularities left on the forging, yet that portion of the lip surface close to the cutting edge constantly receives much less pressure from the chip than the same surface receives at a slight distance away from the cutting edge. This allows the tool to run at higher cutting speeds than would be possible if the cutting edge received the same pressure as does the lip surface close to it.

172 There are many phenomena which indicate this tearing action of the tool. For example, it is an everyday occurrence to see cutting tools which have been running close to their maximum speeds and which have been under cut for a considerable length of time, gut-

tered out at a little distance back of the cutting edge, as shown in Folder 3, Fig. 17e. The wear in this spot indicates that the pressure of the chip has been most severe at a little distance back from the edge.

173 Still another manner in which in many cases the tearing action of the tool is indicated is illustrated in Folder 3, Fig. 17a, in which a small mass of metal *D* is shown to be stuck fast to the lip surface of the tool after it has completed its work and been removed from the lathe. When broken off, however, and carefully examined, this mass will be found to consist of a great number of small particles which have been cut or scraped off of the forging, as above described, by the cutting edge of the tool. They are then pressed down into a dense little pile of compacted particles of steel or dust stuck together and to the lip surface of the tool almost as if they had been welded. In the case of the modern high speed tools, when this little mass of dust or particles is removed from the upper surface of the tool, the cutting edge will in most cases be found to be about as sharp as ever, and the lip surface adjacent to it when closely examined will show in many cases the scratches left by the emery wheel from the original grinding of the tool.

174 With roughing tools made from old fashioned tempered steel, however, and which have been speeded close to their "standard speeds," in most cases after removing this "dust pile" from the lip surface, the cutting edge of the tool will be found to be distinctly rounded over. And in cases where the tool has been cutting a very thick shaving, the edge will be very greatly rounded over, as shown in the enlarged view of the nose of a tool in Folder 7, Fig. 41.

NATURE OF WEAR ON TOOLS DEPENDS UPON WHETHER IT HAS BEEN CHIEFLY CAUSED BY HEAT

175 The appearance of tools which are worn down so as to require regrinding differs widely according to whether or not the heat produced by the pressure of the chip has been the chief cause of wear; and according to the part which heat has played in producing the wear, worn out tools may properly be divided into three classes.

WEAR OF THE FIRST CLASS

176 Tools in which the heat, produced by the pressure of the chip, has been so slight as to have had no softening effect upon the surface of the tool.

WEAR OF THE THIRD CLASS

177 Tools in which the heat has been so great as to soften the lip surface of the tool beneath the chip almost at once after starting the cut, and in which, therefore, heat has played the principal part in the wear of the tool.

WEAR OF THE SECOND CLASS

178 Tools in which the heat only slightly softens the surface of the tool during the greater part of the time that it is cutting, while during the latter part of the time heat is the chief cause of wear because, as described in the third class, it greatly softens the lip surface under pressure of the chip.

179 In the FIRST CLASS, in which heat plays no part in the wear of tools, all tools (whether made from carbon tempered steel, or from the old style self-hardening steel, or from the modern treated tools) wear in about the same manner. Namely, the lip surface just back of the cutting edge is slowly rubbed or worn or ground down through the friction of the chip, as shown in Folder 3, Fig. 17d.

180 As the surface of the tool through the long rubbing of the chip becomes slightly roughened, the tool wears away somewhat more rapidly, but the increase in the rapidity of wear is in this case by no means marked.

181 On the other hand, tools which wear according to the THIRD CLASS begin to distinctly deteriorate within from one to three minutes after the chip has started to cut, depending upon the length of time required for the friction of the chip to raise the tool from its normal cold state to the high temperature which corresponds to the combination of pressure and speed which produces the heat. And the moment the nose of the tool has reached a degree of heat at which the metal under the chip becomes distinctly soft, the wear then proceeds with great rapidity. Sometimes after arriving at a certain degree of softness, the heat remains approximately constant, and the wear upon the tool continues at a uniformly rapid rate until a comparatively deep groove or gutter has been worn into the lip surface. At other times after the lip surface of the tool begins to soften, it appears to become rougher and cause a still greater amount of friction and heat, in which case the wear of the tool proceeds at an increasingly rapid rate, and the tool is soon destroyed. There are rare instances in which after the rapid wear has started, the friction between the chip and the tool, for some unaccountable reason, appears to become less and the tool slightly cools down. Cases have come under the

observation of the writer in which tools which had been running with their noses at a visible dark red heat, cooled off to such an extent that the chip which had been very dark blue in color changed to a color but slightly darker than a brown. This indicated a very marked diminution in friction, although the cutting speed was maintained at a uniform rate throughout. This case, however, is of rare occurrence.

182 While a deep groove worn by the chip is a characteristic of wear of the third class, by no means all of the tools in this class wear into a deep groove. Most of them give out before the groove has had time to wear deep. After wear of the third class has started, tools will generally be completely ruined in a time varying from 20 seconds to 15 minutes, and the time which elapses between the softening of the lip surface and the final ruining of the tool is exceedingly irregular. One of two tools—which have been proved through standardization to be uniform within, say, 1 or 2 per cent, may give out within one minute after this action starts, while the other may last 15 minutes. On the other hand, occasional lots of tools are found which, after having been proved uniform through standardization, will last under this softening speed for approximately the same length of time.

REASON FOR ADOPTING A STANDARD TEST PERIOD OF 20 MINUTES

183 It is this irregularity in the ruining time of tools belonging to the third class which has led us to adopt a trial period of 20 minutes as being the SHORTEST RUINING TIME from which it is safe to draw any correct scientific conclusions from tests in the art of cutting metals. See paragraphs 703–704.

184 A cutting speed which causes the tool to be ruined in a shorter period than 20 minutes is accompanied by such a high degree of heat as to produce irregularity in the ruining time; on the other hand, a speed which ruins at the end of 20 minutes is accompanied by that degree of heat at which tools, generally speaking, can be depended upon to wear uniformly. In other words, it represents the degree of heat at which a lot of uniform tools will all give out at about the same time.

ECONOMICAL CUTTING SPEEDS

185 Cutting speeds which are sufficiently slow to cause the tool to wear as described in the first class are entirely too slow for economy. On the other hand, tools when run at the high cutting speeds which

produce wear of the third class last so short a time that these high speeds are entirely out of the question for daily shop use.

186 It is then with cutting speeds causing wear of the SECOND CLASS that we are chiefly concerned; as it is within this range of cutting speeds that almost all roughing tools in every day use should be run for maximum all-round economy. CUTTING SPEEDS OF THIS CLASS ARE REFERRED TO AS "ECONOMICAL SPEEDS" OR "MOST ECONOMICAL SPEEDS." Our experiments, therefore, have been practically confined to a study of cutting speeds of the second class.

187 By referring to paragraph 701, and Folder 15, Table 105, it will be noted that a cutting speed which will cause a given tool to be ruined at the end of 80 minutes is about 20 per cent slower than the cutting speed of the same tool if it were to last 20 minutes. By referring also to paragraph 717, it will be noted that, on the whole, we have concluded it is *not* economical to run roughing tools at a cutting speed so slow as to cause them to LAST FOR MORE THAN ONE AND ONE-HALF HOURS without being reground. Tools which are ruined in one and one-half hours, however, are still within the second class as far as the causes for wear are concerned; and the wear of tools of the second class may be again referred to as being during the greater part of the life of the tool similar to the wear of the first-class tools, in which the heat is not sufficiently great to materially soften the lip surface. In the second class, however, the cutting speeds are so high as to cause the lip surface of the tool to gradually become rougher and rougher, and as this surface roughens, the heat increases so that in their final wearing out, say, during the last five to fifteen minutes of their life, tools of the second class wear in a manner similar to those of the third class. Thus it is seen that wear in tools of the second class is a combination of the type of wear of the first class with the type of wear of the third class, the first class type of wear extending through the greater part of the time that the tool is cutting.

HOW CARBON STEEL TEMPERED TOOLS AND TOOLS MADE FROM OLD FASHIONED SELF-HARDENING STEEL WEAR

189 With carbon steel tempered tools at standard speeds the cutting edge begins to be injured almost as soon as the tool starts to work, and is entirely rounded over and worn away before the tool finally gives out, and the tool works well in spite of its cutting edge being damaged. While with high speed tools at standard speeds, the cutting edge remains in almost perfect condition until just before the tool gives out, when even a very slight damage at one spot on the

cutting edge will usually cause the tool to be ruined in a comparatively few revolutions.

190 Carbon tempered tools and also, to a considerable extent, the old fashioned self-hardening tools (such as Mushet), when run at their "economical" or "standard" speeds, pass through the following characteristic phases as they progress toward the point at which they are finally ruined. It will of course be understood that the "rounding of the cutting edge," the "mounting of the steel upon the lip" and the "rubbing away beneath the cutting edge" all progress simultaneously, although each of these phenomena is separately described.

191 The line of the cutting edge of the tool, which is at first keen, becomes very slightly dull so that it shines when held in the light, and it is then gradually rounded over until it finally loses all resemblance to a cutting edge, and after severe use frequently looks as if it had been purposely rounded over. This action is referred to in recording our experiments as "CUTTING EDGE ROUNDED."

192 The lip, or top surface of the tool, soon becomes slightly roughened and whitened as the shaving presses against it, then the surface of the tool near the cutting edge becomes discolored as if the temper of the tool were being drawn, and this discoloration increases both in the extent of its area and in its approach toward almost a black color, until the tool is entirely ruined. This action is referred to as "DISCOLORED BACK FROM CUTTING EDGE."

193 The flank of the tool begins to discolor in a manner similar to the lip and this discoloration continues to increase until the tool is finally ruined. This action is referred to as "DISCOLORED BELOW CUTTING EDGE."

194 Long before the tool is ruined, also, the fine particles of steel or dust scraped off by the cutting edge begin to weld or stick to the lip of the tool and mount upon it sometimes from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch in height, as shown in Folder 3, Fig. 17d; referred to as "STEEL MOUNTED ON LIP."

195 The flank of the tool just below the cutting edge begins to wear or rub away slightly, and this wear gradually extends further and further below the cutting edge until the tool is ruined; referred to as "RUBBED BENEATH CUTTING EDGE."

196 Small portions of the metal being cut wedge themselves in between the flank of the tool and the work, and are partly welded or stuck to the tool, and these lumps which are welded on to the tool, and the rubbing away of the flank as the tool grows dull, prevent the feed from being uniform in thickness, and cause the tool sometimes to entirely skip its feed for one or two revolutions; referred to as "TOOL

JUMPED." These lumps also force the work and the tool away from one another, and so leave the work rough and lumpy in these places; referred to as "LEFT LUMPY FINISH." Also the particles of metal which are welded on to the flank of the tool frequently leave scratches on the finished part of the work; referred to as "LEFT SCRATCHY FINISH."

197 The tool is finally completely ruined by having so much of its flank rubbed away beneath the cutting edge, that no amount of pressure can force it into the work, and when it reaches this condition it must be immediately removed from the tool post, or there is danger of breaking either the tool, the machine, or the work.

198 As a result of our experiments it became evident that in case of tools made from the "low speed" self-hardening steels, for instance, such as the old fashioned Mushet steel, the tools would in many cases run successfully long after the line of the cutting edge had become slightly injured; also that in the case of "roughing" tools made from the carbon or tempered steels, it was economical and right in daily shop practice to run these tools at such a cutting speed that their actual cutting edges rounded off quite soon after starting to do their work. These tools continued to cut with their edges rounded, somewhat as shown in Folder 7, Fig. 42, successfully through the whole cut.

199 As stated in paragraph 67, all of our experiments made with these two types of tools (carbon and Mushet types) to determine the laws for cutting metals were rendered much more difficult, owing to the judgment required in deciding the exact amount of damage which was appropriate both to the tool and the particular thickness of shaving which was being taken.

200 In paragraph 506 will be found a further discussion of the very great part which the heat caused by the friction of the chip against the lip surface of the tool plays in ruining tools, and in paragraph 965 we refer to the peculiar property of retaining their hardness even at a high heat, which is called "red hardness," as being the essential novelty in the discovery of new "high speed" tools.

HOW MODERN HIGH SPEED TOOLS WEAR

201 As stated above, in the case of modern high speed tools, the damage caused to the tool through the action of cutting is confined almost entirely to the lip surface of the tool. Doubtless also the metal right at the cutting edge of the tool remains harder than it is directly under the center of pressure of the chip, because the cutting

edge is next to and constantly rubs against the cold body of the forging, and is materially cooled by this contact.

202 Whether the lip surface be ground away at high speeds or at slower speeds, the nose of the tool is generally "ruined" in a very short time after the cutting edge has been so damaged that it fails to scrape off smoothly even at one small spot the rough projections which have been left on the body of the forging by tearing away the chip. The moment the body of the forging begins to rub against the clearance flank of one of these high speed tools at or just below the cutting edge, even at one small place, the friction at this point generates so high a heat as to soften the tool very rapidly. After a comparatively few revolutions (particularly when cutting medium or soft steel or cast iron), the cutting edge and flank of the tool beneath it will be completely rubbed and melted away, as shown in Folder 3, Fig. 17b.

203 The above characteristic of holding their cutting edges in practically perfect condition while running at economical speeds up to the ruining point is a valuable property of the high speed tools, since it insures a good finish, and the maintenance throughout the cut of the proper size of the work, without the constant watchfulness required on the part of the operator in the case of old slow speed tools with their rounded and otherwise injured cutting edges, which when run at economical speeds were likely at any minute to damage the finish of the work.

204 When one of these high speed tools is nearing its ruining point, a very trifling nick or break in the line of the cutting edge will be at once noticed by its making a very small but continuous scratch, projecting ridge, or bright streak, on the flank of the forging (namely, upon that part of the forging from which the spiral line of the chip has just been removed). When the skilled operator notices this line, he at once removes the tool from its cut, and notes upon the record "tool began to ruin"; the abbreviation for which in our case consists of the letters B R.

205 The letter R is used to indicate a tool which has been entirely ruined; the word "Good" (G) indicates a tool which is removed from the cut showing but very small damage or wear even to the lip surface; the word "Fair" (F) indicates a tool which shows considerable wear upon the lip surface, such, for instance as is shown in tool, Folder 3, Fig. 17c, the cutting edge of which has, however, not as yet absolutely started to ruin.

206 It is a curious fact that high speed tools which differ in their chemical compositions, and perhaps also slightly in their high heat

and subsequent treatment, give very different indications while cutting that they have begun to ruin. For instance, the kind of scratch, shiny streak, or ridge, which on high speed tools made from steel of one chemical composition would indicate the approach of the ruining point, may possibly be no indication of the approach of the ruining point if made by another type of high speed tool.

207 It is therefore necessary for the operator with each new batch of tools which are to be used in an experiment to absolutely ruin a number of these tools so as to be thoroughly familiar with that exact appearance of the flank of the forging which unquestionably indicates the approach of the ruining point. After the operator has assured himself beyond doubt of this indication, it will not then be necessary for him to ruin each tool completely. The writer has in mind many instances, however, in which from the appearance of the scratches or shiny streaks, etc., on the flank of the forging, he was convinced that the tool was about to ruin, and in which the same tool continued to run for many minutes afterward, and even, in some cases, at an increase in cutting speed. In this element in making experiments, as in all others, nothing must be taken for granted, everything must be proved.

208 In paragraphs 353 and 354 two other reasons for the cutting edges of tools giving out are referred to:

a The spalling off or crumbling away of the tool due to the pressure of the chip at its extreme cutting edge, as shown in Folder 6, Fig. 31a; and

b The spalling off or crumbling away of the extreme cutting edge due to the feeding pressure at this point, as shown in Folder 6, Fig. 31b.

209 As both of these types of yielding must be chiefly considered in their relation to the acuteness of the lip angle of the tool, we refer to them later in the paper.

HOW TO MAKE AND RECORD EXPERIMENTS

ART OF EXPERIMENTING DEFINED AS DETERMINING EFFECT OF VARYING ONE ELEMENT WHILE ALL OTHERS ARE HELD CONSTANT

210 In paragraph 55 (Part 1) we have broadly defined the art of experimenting on this subject as an attempt to hold uniform and constant all of the elements which affect the final results under investigation except the one variable which is being studied, while this one is systematically changed and its effect upon the problem carefully noted.

211 It is the necessity of holding these variables constant which makes all these experiments so difficult, causes the apparatus and forgings tested to be so large and expensive, and consumes perhaps four-fifths of the time of the experimenter. Time and again in our work it has required days and sometimes weeks to prepare for an experiment which, after we have succeeded in obtaining uniformity in all the elements, has been made in a few days or hours.

212 A description of how to maintain uniform conditions is then virtually a description of the art of experimenting on cutting metals. The writer will, therefore, begin by explaining in detail the precautions which must be taken to secure this uniformity.

THE METAL WHICH IS TO BE CUT

213 In determining the effect which any one of the more important elements has upon the cutting speed,—such, for instance, as the effect of the feed or thickness of shaving upon the speed,—it is necessary to make many standard cuts of 20 minutes' duration in succession for each thickness of shaving, in order to find the exact speed at which the tool will be ruined at the end of 20 minutes, as described in paragraph 137. For this reason the information required for each thickness of shaving may cause hundreds of pounds of metal to be cut up into chips; and since in determining the law many different thicknesses of shaving must be experimented with, and the metal cut must be of uniform hardness, in order to obtain accurate results not only a large experimental forging is called for, but the metal throughout the forging must be as nearly as possible uniform.

214 We have finally adopted as the standard size of forging best suited for experiments a piece about 10 feet long by 24 inches in diameter and weighing about 15,000 pounds. For this purpose we prefer a forging made from a large ingot cast from a carefully melted heat of open hearth steel, and forged with a large reduction in the diameter so as to obtain as nearly as practicable uniform working of the metal throughout from the outside to the central portions of the forging. This forging in all cases requires thorough annealing, and in some cases an oil hardening previous to the annealing. Before using it, experimental standard tensile test bars should be cut from each end of the forging and broken so as to prove the uniformity of the metal, and, if necessary, the metal should be re-treated by tempering and annealing until it has been demonstrated through breaking a sufficient number of test specimens to be uniform.

215 Masses of cast iron upon which tools are to be tested should

in all cases have their central portion cored out, so that the metal will be cooled from the center outward as well as from the outside inward, thus producing an annular ring of cast iron from three to four inches thick; which, if sufficient precautions are taken to insure regular cooling, will be comparatively uniform throughout. We have used annular masses of cast iron, made in this manner, of 24-inch diameter with 12-inch cores, 12 feet long; of 15-inch diameter, 10-inch cores, 8 feet long; of 13-inch diameter, 7 feet long; of 13-inch diameter, 9-inch cores, 10 feet long. On the whole, we have obtained the most uniform results from a casting of 24-inch diameter, 16-inch core, and 10 feet long, walls of casting having a maximum thickness of 4 inches poured on end. We have found the central portion of the annular rings which were 6 inches in thickness to be very materially softer than the outer or inner portions of the ring. It has proved to be much more difficult to obtain sufficiently large and uniform masses of cast iron than of steel.

216 A large diameter is called for in both forgings and castings, not only for the sake of obtaining a large quantity of uniform metal, but also to avoid as far as possible the effect of chatter upon the tool, caused by the deflection of the work; and the writer wishes to emphasize the necessity for large masses of metal if the experimenter hopes for trustworthy results.

THE EXPERIMENTAL LATHE

217 The large and uniform forgings and castings required in investigating the laws affecting cutting tools call for a large and powerful lathe in which to make the experiments. This machine must be both large and powerful for various reasons.

218 (A) Our experiments necessitate the taking of cuts with coarse feeds and great depths of cut as well as those with fine feeds and shallow depths.

219 (B) In all experiments there must be a substantial surplus in the driving and feeding capacity of the machine beyond that which is directly used in taking the cut, so that when the time arrives for the tool to give out, the driving mechanism of the lathe shall be sufficiently powerful to completely grind away that portion of the tool which is cutting without overstraining the machine, and thus ruin the tool according to our standard referred to in paragraph 151.

220 (C) This ruining of the tool must be accomplished without either diminution of the speed of cutting or any material deflection or yielding either in the forging itself, in the driving mechanism of the

lathe, or in the tool or the tool post and its supports; or in the feeding mechanism.

221 In brief, the lathe should be a much more powerful machine in all its elements than that which would be required in the daily process of taking cuts of the maximum sizes which are to be experimented upon.

THE SPEED CHANGES OF THE MACHINE

222 The lathe should be capable of running at any rate of cutting speed between the limits, say, of 3 and 300 feet per minute. This wide range of speeds is called for through the necessity of taking both light and heavy cuts upon metals in the two cases of extreme hardness and extreme softness. It is also particularly necessary that the driving mechanism should be such as to maintain as nearly as possible a uniform cutting speed throughout the experiment, even though there may be very great variations in the driving power which is used during different parts of the same experiment.

223 To illustrate: In order to be certain that precisely the same cutting speed is maintained from the beginning to the end of our standard run of 20 minutes, it is necessary, after securing the tool in its proper position in the tool post, to bring its nose into the position which it should occupy in order to take the exact depth of cut which the experiment calls for. The speed of the lathe must then be accurately adjusted so that the precise number of feet per minute will be indicated by the "rotameter" when held against the surface of the forging, as described in paragraph 230, and the driving power and speed control of the lathe should be so uniform that when the feed motion of the lathe is thrown into action, the cutting speed of the tool will neither be appreciably increased nor diminished as the lathe changes suddenly from running without load to running under the full pressure of the cut.

THE FEEDING MECHANISM

224 Such gearing should be used in the feed motion as will insure absolute uniformity in the feed. On no part of the feed mechanism should apparatus be used which depends for its action upon friction, and the feed mechanism should be sufficiently large and massive not only to advance the tools when under the heaviest cut and when they are dull, without danger of breaking, but to be sure that the tool is advanced at an absolutely uniform rate, whatever may be the feed resistance which it must overcome. In other words, precisely the

same uniformity in the rate of feed is demanded as in the rate of cutting speed, and the gearing should give as many positive changes in the thickness of the feed as practicable.

225 As referred to in paragraph 581, the feed gearing must be sufficiently powerful to produce a feeding pressure at the cutting edge of the tool equal to the maximum driving pressure.

THE WEIGHT OF THE MACHINE

226 It is also particularly desirable that all parts of the machine should be sufficiently massive to absorb the slight inequalities in the driving and feeding pressures caused both by the minute wavelike variations of the cutting resistance of the chip and any inequalities in the driving mechanism, without allowing these variations to show themselves in the form of chatter in the tool. It is necessary, therefore, that the tool post and its supports as well as the lathe bed should be massive and wide.

THE BEST TYPE OF EXPERIMENTAL LATHE

227 As stated in paragraph 28, we have had at various times some ten different machines fitted up for the purpose of carrying on our experiments. Our best apparatus was that employed in the three years' experiments at the works of the Bethlehem Steel Company. A duplicate of this lathe and apparatus was used in the Paris Exhibition in 1900 in showing to the public the high speeds at which tools treated by the Taylor-White process could be run.

228 This apparatus is illustrated in Folder 9, Fig. 50; in which M represents a 40 horse power electric motor which is geared to E, a large and powerful pair of "Evans Tapered Friction Driving Pulleys," by means of which a speed variation of 1 to 4 can be obtained. B is the belt driving from one set of cone pulleys upon the Evans driving shaft down to the lathe cone pulleys C. From this cone pulley the power is either transmitted directly or through a double train of gears, G_2 and G_3, to the large geared face plate of the lathe, which is 62 inches in diameter. This lathe swings clear of the saddle, a forging 52 inches in diameter, and was designed especially heavy throughout its bed, saddle, head and tail stocks, for the purpose of taking heavy roughing cuts upon steel forgings.

229 The writer's object in illustrating this lathe is to advise future experimenters to adopt a mechanism throughout which is at least as massive and powerful as the one used by us. If, for example,

the lathe mentioned in the "Manchester" experiments is examined, it will be seen that it is too small to admit a forging large enough in diameter to make the great number of tests upon metal of uniform quality which are necessary in any one of the series of experiments to determine the effect of the more important elements upon the cutting speed; such, for instance, as the effect on the cutting speed of varying the thickness of the chip or the depth of cut. And again, Professors Breckenridge and Dirks in the experiments made by them at the University of Illinois (published November 15, 1905), were so hampered by the size of the lathe at their disposal as to make it impossible to use test pieces of cast iron which contained enough metal to properly determine any of the laws.

MEASURING THE CUTTING SPEED

230 On Folder 9, Fig. 54, is shown in full size an instrument called a "rotameter," which we have found the best appliance for practical use in measuring the cutting speed. The small wheel W, which projects beyond the rim of the rotameter is firmly pressed directly against the surface of the rotating forging. The circumference of the small disk or wheel in the rotameter moves with the same velocity as the surface of the forging, and through gearing inside of the instrument rotates the two hands upon the face of the rotameter—corresponding to the hands of a watch—one of which points to the feet and the other to the inches of travel. In taking a reading with this instrument, its two hands are set at zero, and a stop-watch is started at the instant that the wheel of the rotameter is pressed upon the moving forging. The rotameter on being removed from the forging at the end of a minute indicates on its face the rate of cutting speed.

231 Owing to the direction in which the chip runs off of the tool, the rotameter can best be used upon the larger of the two diameters of the forging; and it is our custom to record the speed of the cut as the speed of the forging upon the larger of these two diameters.

232 It is necessary to accurately standardize each of these rotameters before using, and frequently afterward, to be sure that its hands indicate the exact distance the circumference of the wheel travels. This is done by measuring accurately on any smooth surface a distance of say 20 to 30 feet, and running the rotameter along this path by hand.

233 The speed of the forging should be checked by the rotameter at frequent intervals throughout the test, to be absolutely sure that it

does not vary, and in all cases a record should be kept of the exact outside diameter of the forging together with the longitudinal distance which the tool travels in 20 minutes in the direction parallel to the axis of the work. These data enable the experimenter to accurately check the actual average cutting speed maintained throughout the test with the speed aimed at and recorded from the rotameter measurements.

234 On Folder 9, Fig. 53, is illustrated an instrument called the "cutmeter," which we have found useful and accurate in measuring cutting speeds. The circumference of the disc *W* is pressed against the surface of the forging whose speed is to be measured. An increase in the revolutions of the shaft to which this disc is attached causes a proportional increase in the force with which an annular magnet mounted on the same shaft as this disk tends to rotate another disc which forms an armature for this magnet. The rotation of this armature is controlled by an accurately standardized steel spring which tends steadily to bring it back to its zero position. The scale of the instrument, which gives the cutting speed directly in feet per minute, is mounted on the circumference of the armature disc, and is read opposite a fine wire in the middle of a glass covered opening in the body of the instrument. Like the rotameter, it must be checked up from time to time to be sure that it remains absolutely accurate.

235 This instrument would be perhaps, on the whole, the most satisfactory which we know of for measuring cutting speeds in experiments as well as for the daily shop use by machinists and foremen, were it not for two defects. First, that the makers for some unaccountable reason have made the wheel *W* smaller than the body of the cutmeter. This defect renders it awkward to apply in all cases, and impossible for accurate use in many cases. And second, that the lines on the speed scale of the instrument are too close together when registering the cutting speeds commonly used for machine shop work. It has, however, two very great advantages:

a No stop watch need be used;

b The exact cutting speed can be read on the scale of the instrument within a few seconds after it is in contact with the work.

236 As a check upon all mechanical[1] appliances used in determining cutting speed, the speeds should be calculated by measuring

[1]Mr. Daniel Adamson, in the discussion of this paper, suggests the use of a revolution counter attached to the spindle of the lathe for counting the revolutions of the forging.

the diameter of the forging and counting its revolutions per minute as obtained by making a chalk or other mark upon the circumference of the face plate of the lathe; and by means of a stop-watch noting the time required for the lathe to make a given number of revolutions, say ten or fifty, according to whether the speed is slow or fast. From these data the accurate cutting speed is figured, preferably by the use of a circular slide rule known as the "omnimeter."

237 At the end of each test we again calculate the actual average cutting speed obtained by ascertaining the average revolutions per minute. This is done by dividing the total travel of the lathe carriage in inches by the thickness of the feed and the number of minutes; and having accurately measured the diameter of the work, the cutting speed is quickly figured by the use of an omnimeter.

MEASURING THE DEPTH OF THE CUT

238 Before starting a 20-minute run, the experimenter should assure himself by accurately calipering the forging that the portion of the test piece about to be cut is of uniform diameter throughout the distance to which the cut will extend. The writer would especially call attention to the error which we at first made, and which he believes has been made by all other experimenters, of attempting to measure the depth of the cut and maintain it uniform throughout the experiment by using calipers. It is out of the question to accurately caliper the forging while it is running at the high speed required for the cut, and with the jar incident to this work, and calipers should only be used on the forging while it is at rest.

239 On Folder 9, Fig. 55, is illustrated a "cut gage" which we have used for maintaining uniform the depth of the cut; a separate gage similar to this is made for each depth of cut to be experimented with.

240 The longer edge of this gage is placed upon the larger diameter of the forging, while the shorter edge, or offset, rests at the same time upon the smaller diameter. By placing it upon the forging in such a position that the light back of it shows between the edge of the gage and the forging, the depth of the cut can be maintained with great accuracy.

241 We look upon a gage of this sort as an absolute necessity for maintaining accuracy in this work. An examination of the records of other experimenters will show the necessity of this instrument, as they almost invariably record in one column the depth of the cut which they wish to have, and in another column the depth of the cut which they succeed in maintaining.

242 It is of course a very simple matter before starting on the experiment to turn the smaller diameter on the forging so as to give any exact depth of cut which may be wanted. If, however (after turning the desired smaller diameter), the nose of the tool is then brought so that it is barely in contact with this surface, the instant that the feed is thrown in for the experimental run and the tool starts to cut, the pressure of the shaving will invariably either force its nose slightly further away from the axis of the forging or else draw it a little closer to it and in this way give a shallower or greater depth of cut than that desired.

243 As before explained, calipering while the forging is running is too inaccurate to enable the operator to readjust the tool so as to again obtain the exact depth of cut, whereas through the use of the cut gage illustrated, the tool can at any time be accurately advanced a little closer to the axis of the forging or drawn away from it, until the exact depth of cut aimed at is attained.

244 The first move, then, on the part of the operator, after starting his tool on a 20-minute run is to exactly readjust the depth of his cut through the use of the cut gage, and he should next immediately use the rotameter, or the cut meter in checking the cutting speed. A trifling variation either in the depth of cut or in the cutting speed does not affect the ultimate result of the experiment provided these variations occur during the first two or three minutes while the tool is warming up and before it has reached its maximum heat. A very slight variation, however, either in the depth of cut or in the cutting speed will be likely to spoil the whole experiment if it occurs, say, after the first two or three minutes of the run. The depth of cut should be checked at least once every two minutes throughout the experiment with the cut gage and oftener as the tool approaches the ruining point.

ON UNIFORMITY IN THE CUTTING TOOLS

245 The greatest difficulty met with in experimenting is to insure uniformity in all of the cutting tools which are used in a given series of experiments made, say, for the purpose of determining one of our laws. There are many elements in making and treating tools to be used for experimenting which affect the standard speed at which a tool will just be ruined at the end of a 20-minute run; and in preparing a lot of tools for an experiment, it is not only essential for the experimeter to assure himself that in the making of each tool every precaution has been taken with one element after another

to secure uniformity; but, in addition to this, it is necessary to prove by actually running each one in a preliminary tool test that they are all uniform, say, within a limit of about 2 per cent.

246 To go into further detail on this point, the following precautions should be taken for securing uniformity in the tools: (The writer refers here particularly to cutting tools made by the Taylor-White process, which have come to be called almost universally tools made from the "new tool steels."[1])

247 Special precaution should be taken in buying the tool steel from which these experimental tools are to be made, to be sure that it is of uniform quality. The very best and most uniform make of tool steel should be purchased, and the maker should be informed of the important use to which this particular lot of tools is to be put, and should be requested to take special care in mixing and melting the steels to be sure that they are uniform in their chemical composition, and subsequently in the hammering and annealing of the bars. A chemical analysis either of each bar, or, at least, of the heat of steel from which the bars are forged, should be made. The same care should be taken in the dressing and subsequent heat treatment of each of the tools to see that they are all alike. It is of special importance that the tools should be ground slowly, and that a very heavy stream of water should be directed throughout the operation of grinding directly upon the cutting edge of the tool, so as to absolutely avoid the danger of overheating the tool at the cutting edge in grinding, as described in paragraph 473. More high speed tools are daily injured in our machine shops through overheating in grinding than in any other way, and this injury is all the more serious because it can only be detected after the tool has been used in the machine by its failure to run at the proper speed.

248 The tools must be ground so that they have noses of the same size; so that the curve or contour of the cutting edge is of exactly the same shape in each tool; and so that the clearance and lip angles are all alike. It is entirely possible for a skilled grinder, with the use of especially made gages, to grind all of these tools to their proper

[1] The expression "new tool steels" is absolutely misleading, since the novelty lies in heating these tools to the melting point or nearly so, and in the other heat treatments explained in the Taylor-White patents, and not in their chemical composition; because tool steels which were appropriate to this treatment were sold in the market long before Mr. White and the writer discovered that high speeds could be obtained through heating them to the high heat. "High heat tools" or "modern high speed tools" describes them much better.

shapes by hand on an ordinary grindstone or emery wheel,[1] but this process is exceedingly slow and requires a good deal of skill.

249 If practicable, therefore, the tools should all be ground with an automatic tool grinder having a "former" of the exact shape of the cutting edge. The writer has found it desirable, however, in almost all cases, in preparing a set of experimental tools, to appoint an inspector to stand over the man who was running the automatic grinder to absolutely assure himself that these tools were ground without the danger of overheating; and also, in spite of the work being done on an automatic grinder, this inspector should examine each tool with templets and gages to be certain that the curves and angles are right.

250 Before using a tool, the operator himself should see to it that the bottom surface of the tool is a true plane, and that the tool is supported by the tool post as far forward as practicable (in fact, almost directly under the cutting edge), thus eliminating one possible element of vibration or chatter. In many cases we have, therefore, found it advantageous to grind the bottom of our experimental tools to a true plane on a surface grinder.

251 After all of these precautions have been taken, it is then necessary to accurately determine the standard speed at which this make of tool will be ruined at the end of a 20-minute run, and if, for example, it has been shown that the standard ruining speed of these tools is 61 feet per minute when run upon a forging which has been previously proved to consist of uniform metal, then each of the tools before being used in experimenting should be successively run upon the same forging at a speed of 60 feet for a period of 20 minutes without ruining.

WHERE PRACTICABLE IN EXPERIMENTING NO CUTS LIGHTER THAN $\frac{3}{16}$ INCH DEPTH BY $\frac{1}{16}$ INCH FEED SHOULD BE TAKEN

252 In determining many of the laws connected with this art it is possible for the experimenter to choose the size of the cut to be used in his trials, and we should recommend for all experiments of this character the use of a cut $\frac{3}{16}$ of an inch in depth by $\frac{1}{16}$ of an inch feed. If a heavier cut than this be taken, too much of the test piece (either forging or casting) will be used up, and there is likely to be difficulty

[1] The writer himself, in his early experiments, spent days in grinding his experimental tools to the right shapes, and it was this experience which first led him to appreciate the necessity for an automatic tool grinder in a machine shop, and then to design one and put it into use.

in obtaining sufficient test metal of uniform quality to complete a full set of experiments. On the other hand, with a depth less than $\frac{1}{16}$ of an inch, the error that is likely to be made even by the best experimenters in maintaining a uniform depth of cut, becomes such a large percentage of the total depth as to materially affect the accuracy of the experiment. This is true to such an extent that as a result of our experience we should consider practically worthless for determining laws all cuts that are as shallow as $\frac{1}{16}$ of an inch, and we should much prefer a $\frac{3}{16}$ inch depth to a $\frac{1}{8}$ inch depth.

253 A feed which is finer than $\frac{1}{16}$ of an inch is also undesirable for experiments because any trifling imperfection or flaw at or near the cutting edge of the tool will more seriously affect the results with a smaller feed than this, and also small hard spots or other blemishes in the metal that is being tested have a much worse effect upon the tools with fine than with coarse feeds.

MORE TIME REQUIRED IN PREPARATION THAN IN EXPERIMENTING

254 From all this it is evident that the time and trouble required in preparing for a set of experiments is far greater than that of actually doing the work; and this should emphasize the necessity for great care in every detail both of making the experiments and in accurately observing and recording every item which may have any bearing upon the final result.

255 Let me again repeat, then, that the art of making these experiments consists mainly in holding constant and uniform all the various elements affecting the problem, while the one element which is being studied is varied.

256 We have been fully alive for some seven or eight years past to the necessity for all these precautions, and the writer believes himself to be justified in saying that no care has been spared in doing our work. Yet in critically examining the results of even our more recent sets of experiments, it becomes apparent that for one cause or another, perhaps more than one-half of the results obtained were such that we should not be willing to accept them as true indications of the laws which we were investigating; and in most of these cases of what may be called partial failure we have not been able to definitely locate the cause. At times it was probably due to a slight irregularity in the composition of the tool steel, or perhaps to a brittleness at the cutting edge of some of the tools which did not show in our preliminary tests of the tools, and in other cases to occasional zones or spots in the experimental forging which were harder than the rest, or

to an undetected variation in the rate of the cutting speed; all of which merely emphasizes the necessity for taking infinite pains in this work.

ON RECORDING THE DETAILS AND RESULTS OF EXPERIMENTS

257 In describing our experiments no effort will be made to give them in their chronological order. As before stated, between 30,000 and 50,000 experiments have been made by us, so that it is entirely out of the question to publish in a paper of this sort a record of the original observations made upon the runs of each of the experimental tools. It would be foolish, in fact, to publish any such voluminous record. Each of the sets of experiments undertaken by us was made for some one specific purpose, and as soon as practicable after completion, the important runs of the tools were copied in groups from the original records upon summary sheets, each group of standard cuts having a bearing upon some one of the items to be investigated. It would be improper in a paper of this sort, however, to publish even all of these sheets of summaries. But in order that our methods of originally recording and then grouping and finally summarizing our experiments may be clearly understood, the writer has decided to publish certain sample sheets from each of these records.

OPERATOR'S DAILY RECORD

258 On Folder 11, Fig. 77, is given a sample of one of our sheets, reduced to two-third size, upon which were entered by the operator the details of the experiments made at the lathe. It may be remarked that no possible harm is done by recording too many items even remotely affecting each test, while the omission of what may at the time seem a matter of no moment may ultimately prove of most serious import. The writer has particularly in mind the fact that in some of his early experiments he failed to either date his experimental sheets or to number consecutively his experiments. Owing to this omission he was obliged later on to throw away all of the results obtained because he was unable to distinguish between the records of a certain set of experiments which he knew to have been accurately made, and another set in which he discovered, after making, a serious error in method.

SUMMARY SHEET

259 On Folder 8, Fig. 45, is shown a sample of one of our summary sheets, upon which have been recorded the runs of one of our best series

of experiments for the purpose of determining the effect of feed and depth of cut in cutting steel with a round nosed tool.

260 On Folder 11, Fig. 76, is shown a sample of one of our summary sheets, upon which have been recorded the runs of one of our best series of experiments for the purpose of determining the effect of feed and depth of cut in cutting cast iron with a round nosed tool.

261 On Folder 11, Fig. 75, is shown a sample of one of our summary sheets, upon which has been recorded another set of experiments for the purpose of determining the laws of feed and depth of cut in cutting steel with a round nosed tool. This set of experiments represents a case in which we have made a partial failure in our work. In fact, it represents one of the poorest of any of our sets of experiments from which we have attempted to draw conclusions. By examining the standard speeds of the tools under the column marked $\frac{9}{32}$ inch depth of cut, it will be observed that the standard speeds in this column are approximately the same as those given for the $\frac{3}{16}$ inch depth of cut. Now, our knowledge of the art teaches us that without question the true cutting speed for a $\frac{9}{32}$ inch depth of cut should be materially slower than that for a $\frac{3}{16}$ inch depth of cut. It follows, therefore, that we have failed at some point in making these experiments. In this particular case the failure may have been due either to irregularity in the standard tools, or more probably to a change in the hardness of the forging operated upon, as we approached its central zone.

262 On Folder 15, Fig. 103, is shown a sample of one of our summary sheets, upon which has been recorded a set of experiments for the purpose of determining the effect of the duration of the cut upon the standard cutting speed, cuts of 10, 20, 40, and 80 minutes' duration each being experimented with. This set of experiments likewise belongs to the class of those which show a certain amount of irregularity, either in the forging, the tools, or in our methods. (See further comments upon the cuts of 10 minutes' duration in paragraph 703.)

EACH LAW AND DIAGRAM THE RESULT OF SEVERAL SERIES OF EXPERIMENTS

263 In finally determining and formulating what we believe to be the true laws, no one set of experiments was found to be sufficient. In almost all cases the results obtained by two or more sets of experiments were plotted together upon logarithmic paper, and by inspecting the lines drawn through the points located upon this logarithmic

paper, the results of several sets of experiments can be coördinated, and the general trend of the law much better indicated than would be possible from any one set of experiments alone. A mathematical expression is then found which corresponds to the line which approximates most closely to the law, as indicated by thus combining several experiments. For a sample of this use of a logarithmic sheet, see Folder 16, Fig. 115.

264 On Folder 16, Fig. 114, will be again seen a sample of the actual curve plotted on ordinary cross section paper corresponding to one of these mathematical expressions, and each of the spots located at various places close to the line of this curve represents the summary or conclusion arrived at as the result of a large number of experiments.

265 An inspection of these curves will indicate the extent to which we have succeeded in a mathematical representation of the laws.

266 These matters will be discussed more fully later in the paper, our object in anticipating being to give at this point a birdseye view, as it were, of a number of the steps taken toward finally making daily use of our experiments through the slide rules.

PROPER SHAPE FOR STANDARD SHOP TOOLS

267 As stated in paragraph 1 (Part 1) of this paper, our principal object in carrying on the investigation has been to obtain the knowledge required in fixing daily a definite task, with a time limit, for each machinist. It is evident that this involves the use of standard cutting tools throughout the shop which are in all respects exact duplicates of one another.

A FEW CAREFULLY CONSIDERED TYPES OF TOOLS BETTER THAN GREAT VARIETY

268 In our practical experience in managing shops we have found it no easy matter to maintain at all times an ample supply of cutting tools ready for immediate use by each machinist, treated and ground so as to be uniform in quality and shape; and the greater the variety in the shape and size of the tools, the greater becomes the difficulty of keeping always ready a sufficient supply of uniform tools. Our whole experience, therefore, points to the necessity of adopting as small a number of standard shapes and sizes of tools as practicable. It is far better for a machine shop to err upon the side of having too little variety in the shape of its tools rather than on that of having too

many shapes. And the energy of the department for maintenance of tools should be directed rather toward securing an ample and uniform supply of tools limited to a few shapes than to a great variety. The writer can hardly lay too much stress upon this point and it, therefore, becomes all the more important to use the greatest care and judgment in selecting the standard shape which is to be used for roughing tools.

STANDARD TOOLS ILLUSTRATED

269 In Folder 5, Figs. 20a to 25e, are illustrated the shapes of the standard tools which we have adopted, and in justification of our selection the writer would state that these tools have been in practical use in several shops both large and small through a term of years, and are giving general, all-round satisfaction. It is a matter of interest also to note that in several instances changes were introduced in the design of these tools at the request of some one foreman or superintendent, and after a trial on a large scale in the shop of the suggested improvements, the standards as illustrated above were again returned to. These shapes may be said, therefore, to have stood the test of extended practical use on a great variety of work.

270 It would seem to be of such great importance to explain fully our reasons for adopting these tools as our standards, that the writer will describe in the pages immediately following a number of the experiments, the results of which have perhaps had the greatest influence in determining the curve or line of the cutting edge. With this end in view, it has been found necessary to record these experiments out of the order and the place in this paper in which they would otherwise be properly and logically described. These remarks refer particularly to experiments described in paragraphs 292 to 306.

CONFLICT BETWEEN THE DIFFERENT OBJECTS TO BE ATTAINED IN CUTTING METALS WHICH AFFECT THE DESIGN OF STANDARD TOOLS

271 Our standard tools may be said to represent a compromise in which each one of the elements given in paragraph 272 has received most careful consideration, and has had its due influence in the design of the tool; and it can also be said that hardly a single element in the tools is such as would be adopted if no other element required consideration.

272 The following, broadly speaking, are the four objects to be had in mind in the design of a standard tool:

a The necessity of leaving the forging or casting to be cut with a true and sufficiently smooth surface;

b Removing the metal in the shortest time;

c The adoption of that shape of tool which shall do the largest amount of work with the minimum combined cost of grinding, forging, and tool steel;

d Ready adaptability to a large variety of work.

273 As we go further into this subject the nature of the conflict between these four objects and of the sacrifice which each element is called upon to make by one of the others will become apparent. To illustrate the nature of these compromises:

274 Generally speaking, we have been obliged to adopt as our standard shape a tool which can be run at only about, say, five-eighths of the cutting speed which our knowledge of the art and our experiments show us could be obtained through another tool of entirely different shape if no other element than that of cutting speed required consideration.

275 We have been obliged to sacrifice cutting speed to securing smaller liability to chatter; a rather truer finish; a greater all-round convenience for the operator in using the tool; and a comparatively cheaper dressing and grinding. The most important of the above considerations, however, is the freedom from chatter.

276 On the other hand, we have been obliged to adopt a rather more elaborate and expensive method of dressing the tools than is usual in order to provide a shape of tool which allows it to be ground a great many times without redressing, and also in order to make a single Taylor-White heat treatment of the tool last longer than it otherwise would. And again, the shape of the curve of the cutting edge of the tool which we have adopted—first, to insure against chatter, and second, for all-round adaptability in the lathe,—calls for much more expense and care in the grinding than would be necessary if a more simple shape were used. This necessitates in a shop either a specially trained man to grind the tools by hand to the required templets and angles or preferably the use of an automatic tool grinder.

277 Before describing in detail the considerations which led to the adoption of our standard tools, it will be necessary to explain some of the more important experiments which have a direct bearing upon this subject. The shape of our standard tools will be again treated in paragraphs 325 to 332.

ELEMENTS AFFECTING CUTTING SPEED OF TOOLS IN THE ORDER OF THEIR RELATIVE IMPORTANCE

278 The cutting speed of a tool is directly dependent upon the following elements. The order in which the elements are given indicates their relative effect in modifying the cutting speed, and in order to compare them, we have written in each case figures which represent, broadly speaking, the ratio between the lower and higher limits of speed as affected by each element. These limits will be met with daily in machine shop practice.

279 (A) The quality of the metal which is to be cut; *i. e.*, its hardness or other qualities which affect the cutting speed.

Proportion is as 1 in the case of semi-hardened steel or chilled iron to 100 in the case of very soft low carbon steel.

280 (B) The chemical composition of the steel from which the tool is made, and the heat treatment of the tool.

Proportion is as 1 in tools made from tempered carbon steel to 7 in the best high speed tools.

281 (C) The thickness of the shaving; or, the thickness of the spiral strip or band of metal which is to be removed by the tool, measured while the metal retains its original density; not the thickness of the actual shaving, the metal of which has become partly disintegrated.

Proportion is as 1 with thickness of shaving $\frac{3}{16}$ of an inch to $3\frac{1}{2}$ with thickness of shaving $\frac{1}{4}$ of an inch.

282 (D) The shape or contour of the cutting edge of the tool, chiefly because of the effect which it has upon the thickness of the shaving.

Proportion is as 1 in a thread tool to 6 in a broad nosed cutting tool.

283 (E) Whether a copious stream of water or other cooling medium is used on the tool.

Proportion is as 1 for tool running dry to 1.41 for tool cooled by a copious stream of water.

284 (F) The depth of the cut; or, one-half of the amount by which the forging or casting is being reduced in diameter in turning.

Proportion is as 1 with $\frac{1}{2}$ inch depth of cut to 1.36 with $\frac{1}{8}$ inch depth of cut.

285 (G) The duration of the cut; *i. e.*, the time which a tool must last under pressure of the shaving without being reground.

Proportion is as 1 when tool is to be ground every $1\frac{1}{2}$ hours to 1.207 when tool is to be ground every 20 minutes.

286 (H) The lip and clearance angles of the tool.
Proportion is as 1 with lip angle of 68 degrees to 1.023 with lip angle of 61 degrees.

287 (J) The elasticity of the work and of the tool on account of producing chatter.
Proportion is as 1 with tool chattering to 1.15 with tool running smoothly.

288 A brief recapitulation of these elements is as follows:
(A) quality of metal to be cut: 1 to 100;
(B) chemical composition of tool steel: 1 to 7;
(C) thickness of shaving: 1 to 3½;
(D) shape or contour of cutting edge: 1 to 6;
(E) copious stream of water on the tool: 1 to 1.41;
(F) depth of cut: 1 with ½ inch depth to 1.36 with ⅛ inch depth of cut;
(G) duration of cut: 1 with 1½ hour to 1.20 with 20-minute cut;
(H) lip and clearance angles: 1 with lip angle 68 degrees to 1.023 with lip angle of 61 degrees;
(J) elasticity of the work and of the tool: 1 with tool chattering to 1.15, with tool running smoothly.

289 The quality of the metal which is to be cut is, generally speaking, beyond the control of those who are in charge of the machine shop, and, in fact, in most cases the choice of the hardness of metals to be used in forgings or castings will hinge upon other considerations which are of greater importance than the cost of machining them. This subject will be further treated in paragraph 1129.

290 The chemical composition of the steel from which the tool is made and the heat treatment of the tool will, of course, receive the most careful consideration in the adoption of a standard tool. No shop, however, can now afford to use other than the "high speed tools," and there are so many makes of good tool steels, which, after being forged into tools and heated to the melting point according to the Taylor-White process, will run at about the same high cutting speeds, that it is of comparatively small moment which particular make of high speed steels is adopted. This subject will be further dealt with in paragraph 965, etc.

EFFECT OF THICKNESS OF SHAVING ON CUTTING SPEED THE MOST IMPORTANT SUBJECT FOR EXPERIMENT

291 It is the THICKNESS OF SHAVING, then (item C in the list above) which must be first considered, as this element has more

effect upon the design of our standard tools, and in fact upon the whole problem of cutting metals than any other single item which is completely under the control of those who are managing a shop.

EXPERIMENTS SHOWING EFFECT UPON CUTTING SPEED OF VARYING THE THICKNESS OF THE SHAVING, A TOOL WITH STRAIGHT-EDGE BEING USED, REMOVING A SHAVING IN ALL CASES EXACTLY ONE INCH LONG

292 The following experiments were made to determine the effect upon the cutting speed of varying the thickness of the shaving. For this purpose a number of broad nosed tools with straight cutting edges, similar to that shown in Folder 7, Fig. 35, were forged from ordinary tempered carbon tool steel. Straight cutting edges were used in order that the shaving should be of the same thickness throughout. The corner of the tool, however, which cuts at the smaller of the two diameters of the forging was rounded to a radius of exactly $\frac{1}{8}$ of an inch. This was necessary in order to thin the shaving down sufficiently at this point to absolutely insure that part of the tool which gives the required smoothness to the forging from giving out before the tool dulls along the straight line of the cutting edge.

293 In these experiments the tool was set in the lathe as shown in Folder 16, Fig. 111, so that exactly one inch of the STRAIGHT PORTION of the cutting edge was at all times under pressure of the shaving. In all cases a feed of 8/100 of an inch was used, so that the thickness of the shaving was in each case directly proportional to the depth of the cut.

294 These experiments were made upon a forging of the following chemical composition:

Carbon	0.369 per cent
Manganese	0.517 per cent
Silicon	0.238 per cent
Phosphorus	0.043 per cent
Sulphur	0.051 per cent

Tensile test bars actually cut from the body of the forging showed the following physical properties:

Tensile strength	82,947 lbs.
Stretch	21.50 per cent
Contraction of area	30.00 per cent

295 A heavy stream of water was thrown throughout the experiments upon the shaving just at the spot at which it was being removed from the forging by the tool.

296 Depths of cut of exactly $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$ and $\frac{3}{8}$ inch were used, cor-

responding to thicknesses of shaving of 0.01, 0.015 0.02 and 0.03 inch.

297 The speeds corresponding to these cuts, each of which was of 20 minutes' duration, are given in Folder 16, Table 113. These cutting speeds are plotted on Folder 16, Figs. 114 and 115, and a curve corresponding to the following formula is drawn approximately through these various points. They are also plotted on logarithmic paper, on Folder 16, Fig. 113, on which the speed points lie approximately in a straight line.

$$V = \frac{1.54}{t^{\frac{1}{4}}}$$

in which

V = cutting speed in feet per minute for 20-minute cut;

t = thickness of shaving in inches.

298 On Folder 16, Table 113, will be seen also the ratio between the cutting speeds of each of these thicknesses of shaving, from which it will be noted, for example, that by dividing the thickness of the shaving by 3, the cutting speed is increased in the ratio of 1 to 1.8. For further description of these experiments, see paragraph 761.

EXPERIMENTS SHOWING EFFECT UPON CUTTING SPEED OF VARYING THE DEPTH OF THE CUT, A TOOL WITH STRAIGHT-EDGE BEING USED, REMOVING IN ALL CASES SHAVING 0.03 INCH THICK

299 Tools of the same shape as those shown in Folder 7, Fig. 35, were set in the exact position shown in Folder 17, Fig 35, and in Folder 17, Fig. 116, we show in section lines the sizes and proportions of the chips, so that with a feed of 0.08 inch the tool in all cases removed a shaving 0.03 inch thick. The experiments were made upon the same forging, and with otherwise exactly the same conditions as those described just above for determining the effect of thickness of shaving upon cutting speed. Such depths of cut were used as to bring consecutively $\frac{1}{8}$ inch, $\frac{3}{8}$ inch and 1 inch in length of the straight portion of the cutting edge under the shaving.

300 These experiments were made upon a forging of the following chemical composition:

Carbon	0.492 per cent
Manganese	0.477 per cent
Silicon	0.194 per cent
Phosphorus	0.042 per cent
Sulphur	0.039 per cent

301 Tensile test bars actually cut from the body of the forging show the following physical properties:

Tensile strength .....97,719 lbs.
Stretch .....15 per cent
Contraction of area .....23.2 per cent

302 The cutting speeds corresponding to these three depths of cut are given on Folder 17, Table 117. These speeds are plotted on Folder 17, Fig. 119, and a curve corresponding approximately to the following formula is drawn through these various points. They are also plotted on logarithmic paper, on Folder 17, Fig. 118, on which the speed points lie approximately in a straight line.

$$V = \frac{12.22}{L^{\frac{1}{4}}}$$

in which

V = cutting speed in feet per minute for 20-minute cut;
L = length of shaving in inches.

303 On Folder 17, Table 117, will also be seen the ratio between the cutting speeds of each of these depths of cut, from which it will be noted, for example, that by dividing the length of the cutting edge by 3, the cutting speed is increased in the ratio of 1 to 1.27.

304 Attention is called to the fact, however, that with round nosed tools as the depth of cut becomes more shallow, there is a greater increase in the cutting speed than in the case of tools having straight line cutting edges, because, as explained in paragraphs 307 and 311, with a round nosed tool the thickness of the shaving becomes thinner and thinner as the extreme nose of the tool is approached. In the case of round nosed tools, therefore, when the depth of the cut is diminished, the cutting speed is increased for two entirely different reasons:

First, because the chip bears upon a smaller portion of the cutting edge of the tool, and

Second, because the average thickness of the chip which is being removed is thinner in the case of round nosed tools with a shallow depth of cut than it was with the deeper cuts.

305 To make it more apparent that the element affecting the cutting speed the most is the thickness of the shaving, the writer would call attention to the fact that dividing the thickness of the shaving by 3 increases the cutting speed in the ratio of 1 to 1.8, while dividing the depth of the cut by 3 only increases the cutting speed in the ratio of 1 to 1.27.

306 From these ratios it will be seen that the thickness of the chip has about three times as great an effect in modifying the cutting speed as has the depth of the cut. For further description of these experiments, see paragraph 761.

WHY CUTTING EDGE OF TOOL SHOULD BE CURVED

PRINCIPAL OBJECT IN HAVING THE CUTTING EDGE OF TOOLS CURVED IS TO INSURE AGAINST DAMAGE TO THE FINISHED SURFACE OF THE WORK

307 The above experiments described in paragraphs 293 to 303 upon the effect of thickness of shaving on cutting speed enable us to explain from the theoretical standpoint the well known fact that each properly designed roughing tool should have the line or contour of its cutting edge curved as it approaches the extreme nose of the tool or that portion of the tool which insures a good and true finish of the work. A tool whose cutting edge forms a curved line of necessity removes a shaving which varies in its thickness at all parts. The only type of tool which can remove a shaving of uniform thickness is one with a straight line cutting edge. The principal object in having the line of the cutting edge of a roughing tool curved as that part of the cutting edge which does the finishing is approached, is to thin down the shaving at this point to such an extent as will insure the finishing part of the tool remaining sharp and uninjured even although the main portion of the cutting edge may have been ruined through overheating or from some other cause.

308 The effect of a curved cutting edge upon the thickness of the shaving will be seen by inspecting Folder 16, Fig. 112, in connection with Figs. 111, 113, 114, and 115.

309 On Folder 16, Fig. 112, is shown a view of the curved cutting edge of a tool enlarged to 16 times its full size; thus at points 0.005, 0.01, 0.02, and 0.04 inch on this curve, the shaving is enlarged in each case so as to be respectively just 16 times as thick as the shavings shown in Fig. 111, shavings 0.005, 0.01, 0.02, and 0.04 inch.

310 It will be observed that the quality and accuracy of the finish left upon the work will depend upon maintaining sharp and uninjured throughout the cut that portion of the cutting edge of the tool which extends, say, from about point 0.005 inch to point 0.02 inch.

311 By examining the standard cutting speeds noted opposite each of the straight-edge shavings, Fig. 111, it will be seen that the

standard or r.....ing speed at point 0.04 inch, for instance, on the curve of our enlarged tool, is 13 feet. From this it is evident, then, that if the tool enlarged in Fig. 112 were run at a cutting speed of 13 feet per minute so as to just ruin it at point 0.04 inch, the tool at point 0.01 inch would then be running at less than one-half of the cutting speed which would be required to ruin it. It would be, therefore, well within its safe limit of cutting speed, and would remain sharp and uninjured until the edge at 0.04 inch had entirely broken down. It is obvious then that a curved line cutting edge insures the finishing part of the tool from damage and for this reason, as above stated, the cutting edges of all tools should be curved, at least as that portion of the edge of the tool is approached which leaves the work of the proper size and with the proper finish.

TOOLS WITH BROAD NOSES HAVING FOR THEIR CUTTING EDGES CURVES OF LARGE RADIUS BEST TO USE EXCEPT FOR RISK OF CHATTER

312 Upon appreciating the increase in the cutting speed obtained through thinning down the shaving, as shown in our experiments with straight cutting edge tools, described in paragraphs 292 and 303, the tools shown on Folder 7, Figs. 32, 33, and 34, were made, and used on roughing work for years in the axle lathes of the Midvale Steel Company. The gain in cutting speed of these standard broad nosed tools over our standard round nosed tool, as shown in Folder 5, Figs. 24 and 23, is in the ratio of 1.30 : 1.

313 This general shape of tool continues to be extensively used, but it is subject to the disadvantage that it is likely to cause the work to chatter, and so leave a more or less irregular finish.

314 Were it not for this difficulty, added to the fact that our standard round nosed tool has a greater all-round adaptability and convenience, the tools illustrated on Folder 7, Figs. 32 to 34, would undoubtedly be the proper shapes for shop standard. This matter will be further discussed in paragraph 665. A method is there described of using two or more broad nosed tools so as to be free from danger of chatter even upon work which is especially liable to chatter.

REASONS WHY CUTTING EDGE WITH COMPARATIVELY SMALL RADIUS OF CURVATURE TENDS TO AVOID CHATTER

315 The avoidance of chatter in the tool plays such an important part in the design of the curve of the cutting edge for standard shop tools that we quote in full from that portion of Dr. Nicolson's admir-

able experiments which appears to the writer to offer an explanation for one of the important causes for chatter.

316 Dr. Nicolson's experiments, which were made with special apparatus (of his own design) for weighing the pressure of the chip upon the tool, were described in his paper (published in Transactions, Vol. 25, pp. 672, 673, 674), as follows:

317 The experiments (numbered 725 to 732 inclusive), the results of which are given in Table 9 are of special interest in regard to: First, the variation of the cutting force as the cut progresses at a very low speed; second, the variation of the cutting stresses with large ranges of speed variation.

318 These experiments were made with a tool having a 55 degree cutting and a 67½ degree plan angle; a cut ⅛ inch deep by ⅛ inch wide being taken.

319 For numbers 725 and 726 the lathe was turned round at a cutting speed of about 1 foot in 5 hours, by means of a wire rope made fast round the large cone pulley, and hauled upon by a man operating a winch.

320 A pointer about 5 feet long was clamped upon the forging, and the four dynamometer gages were read at every half an inch of motion of the end of this pointer, *i. e.*, at about six one-hundredths (0.0625) of an inch of the cut. The vertical force varies from 9080 to 8920 every ⅛ of an inch of motion of the tool, the same wave length characterizing the variation of the surfacing and traversing forces. The observations have been plotted in Fig. 340 [see Folder 12, Fig. 86, present paper] on a base of actual relative tool motion.

321 A similar experiment, No. 636, carried out with the first dynamometer, is shown in Fig. 341. [See Folder 12, Fig. 82, present paper.] Here the cut was heavier, ⅛ inch by ¼ inch, and the tool had a 45 degree plan, and 60 degree cutting angle. The wave length of the force-curve is about 0.6 inch for this experiment, and it varies between 13,000 and 8000 pounds. It will be observed that the force attains a maximum soon after the cutting commences to crack or shear across, and that it drops to a minimum when the small piece of cutting falls off the forging. At such a slow speed as this the cutting has time to shear off right across in separate fragments, whereas it forms a continuous curl of considerable rigidity when the cutting speed is higher than a few feet per minute. These fragments measured, in this experiment, about ¼ inch across the widest part of their surface next the top of the tool in the direction of motion.

322 In these experiments Dr. Nicolson cuts the metal at a speed of one foot in five hours. By referring to Folder 12, Fig. 82, (Fig. 341, of his paper) it will be seen that the pressure on the tool increases and diminishes in the ratio of about 8 to 13 at comparatively regular wave-like intervals, and by comparing this diagram with Folder 12, Fig. 86 (Fig. 340 of his paper) in which a thickness of feed only one-half as great is used, it will be seen that the wave lengths are in this case very much shortened. From this it appears that each thickness of shaving has its own corresponding wave length for the periods of maximum and minimum pressure on the tool.

323 Since the thickness of the shaving is uniform with straight

edge tools, it is evident that the period of high pressure will arrive at all points along the cutting edge of this tool at the same instant and will be followed an instant later by a corresponding period of low pressure; and that when these periods of maximum and minimum pressure approximately correspond to or synchronize with the natural periods of vibration either in the forging, the tool, the tool support, or in any part of the driving mechanism of the machine, there will be a resultant chatter in the work. On the other hand, in the case of tools with curved cutting edges, the thickness of the shaving varies at all points along the cutting edge, as we have pointed out in paragraphs 292 and 303. From this fact, coupled with Dr. Nicolson's experiments, it is obvious that when the highest pressure corresponding to one thickness of shaving at a given point along a curved cutting edge is reached, the lowest pressure which corresponds to another thickness of shaving at another part of the cutting edge is likely to occur at about the same time, and that therefore variations up and down in pressure at different parts of the curve will balance or compensate one for the other. It is evident, moreover, that at no one period of time can the wave of high pressure or low pressure extend along the whole length of the curved cutting edge. For this reason a curved cutting edge tends to prevent chatter.

324 Dr. Nicolson's experiments afford us a much needed theoretical explanation of what has for years been a well recognized fact, namely, that tools with straight cutting edges are much more likely to chatter than those with curved edges, and if Dr. Nicolson's apparatus and experiments had given no further information than this, they would be well worth all of the trouble and time expended upon them.

REASONS FOR ADOPTING THE PARTICULAR CURVES CHOSEN FOR THE CUTTING EDGES OF OUR STANDARD TOOLS

325 Having explained the necessity for curved cutting edges in standard roughing tools, it is desirable to give our reasons for the adoption of the particular curves of our standard tools, illustrated in Folder 5, Figs. 20a to 25e, and Folder 17, Fig. 120. It will be noted that as the body of the tool becomes smaller, the radii of curvature of the cutting edge also become correspondingly smaller. This change in the curve of the cutting edge is rendered necessary by the fact that the smaller tools are used in the small lathes, which, generally speaking, work upon small forgings, from which cuts are removed which are both shallow in depth and have comparatively fine feeds.

Forgings which are small in diameter are quite as liable to chatter as the larger forgings which are machined in larger lathes, and in order to avoid this chatter, it is necessary that a curve for the cutting edge should be chosen which will give a variation relatively in the thickness of shaving even in small depths of cut. Thus, for the avoidance of chatter, the curve of the cutting edge should be small in proportion as the depth of cut and feed which it it normally takes are small.

326 As will be seen later, the smaller radius of curvature of the cutting edge involves a diminution in cutting speed. Therefore, with larger sized tools it becomes important, on the other hand, to take as large a radius of curvature for the cutting edge as is compatible with freedom from chatter. The coarser feed which usually accompanies the larger tool also calls for a larger radius of curvature at the nose of the tool, in order that the ridges left by the spiral path of the tool along the forging shall be as low as practicable.

327 The all-round adaptability of the standard tool to a variety of uses also calls for a smaller radius of curvature the smaller the tool, since standard roughing tools are continually required to run up against a shoulder or into a corner on the work, and the fillet in this corner is normally small in proportion as the forging or casting is small.

328 Generally speaking, also round nosed roughing tools of the type shown do not require the special care in adjusting in the tool post that would be demanded of tools designed with a straight line cutting edge for the purpose of producing a smooth finish, etc.

329 By comparing curves of the tools on Folder 5, Fig. 21a, with Folder 5, Fig. 21b, it will be observed that tools which are to be used for cutting cast iron and hard steel have slightly larger radii of curvature than those which are to be used for the softer steel and wrought iron. The reason for this change is that much slower cutting speeds must be used in cutting hard steels than for soft, and this is also to a less degree true for cast iron as compared with soft steel.

330 It is a matter of common experience that the slower the cutting speed, the less the liability of the tool to chatter. It therefore becomes safe from the standpoint of chatter to use in cutting hard steel and also cast iron a larger radius of curvature than would be permissible in cutting soft steel. The fact has already been pointed out that the larger the radius of curvature, the thinner the shaving, and therefore the higher the cutting speed, and in the interest of economy, it is of course particularly desirable in cutting hard steels to increase the necessarily slow cutting speed as much as practicable.

331 For the following entirely different reason, also, the radius of curvature for tools to be used in cutting cast iron is made larger than in tools to be used in cutting soft steel. Cast iron is cut, as will be seen in paragraphs 491 and 512, with less cutting pressure or resistance to the tool than is required for soft steel. Therefore, in a given lathe a greater depth of cut and coarser feed can be taken on cast iron than on soft steel; and, as explained above, the coarser the feed, the greater should be the radius of curvature of the extreme nose of the tool in order to leave an equally smooth finish.

332 In many machine shops a very considerable portion of the work consists of cuts to be taken upon pieces of cast iron; the depth of the cut being comparatively shallow and the strength and rigidity of the casting begin so great that in order to use even approximately the full pulling power of the lathe or planer, etc., broad feeds must be taken. In our standard shop tools, as illustrated in Folder 5, Fig. 21a, the extreme end of the noses are rounded with too small radii to take a very broad feed, and yet at the same time leave a reasonably smooth finish. It is therefore desirable in all such shops to have standard tools available which are especially designed for work of this character.

333 In Folder 5, Fig. 22, is illustrated a single size of the type of tool which we recommend for this purpose. It will be observed that in form it corresponds exactly to our other standard tools for cutting cast iron and hard steel except that the extreme nose of the tool is widened out so as to have a curve of very large radius, approximating to a straight line.

LIP AND CLEARANCE ANGLES OF TOOLS

334 Contrary to the opinion of almost all novices in the art of cutting metals, the clearance angle and the back slope and side slope angles of a tool are by no means among the most important elements in the design of cutting tools, their effect for good or evil upon the CUTTING SPEED and even upon the pressure required to remove the chip being much less than is ordinarily attributed to them.

CLEARANCE ANGLE OF THE TOOL

335 The following are our conclusions regarding the clearance angle of the tool.

a For standard shop tools to be ground by a trained grinder or on an automatic grinding machine, a clearance angle

of 6 degrees should be used for all classes of roughing work. (See paragraphs 336 to 340)

b In shops in which each machinist grinds his own tools a clearance angle of from 9 degrees to 12 degrees should be used. (See paragraph 339)

336 In seeking for the proper clearance angles for tools, we have as yet been unable to devise any type of experiment which would demonstrate in a clear cut manner (as, for example, the experiments cited for lip angles in paragraphs 361 and 367) which clearance angle is the best. The following, however, are the considerations which affect the choice of clearance angles.

337 On the one hand, it is evident that the larger the clearance angle, the greater will be the ease with which the tool can be fed (wedged or driven) into its work, the first action of the tool when brought into contact with the forging being that of forcing the line of the cutting edge into the material to be cut. On the other hand, every increase in the clearance angle takes off an equal amount from the lip angle, and therefore subjects the tool to a greater tendency to crumble or spall away at the cutting edge, as indicated on Folder **6**, Figs. 31a and 31b. It must be remembered also that the tool travels in a spiral path around the work which it is cutting in the lathe, and that the angle of this path with a perpendicular line in the case of coarse feeds taken upon small diameters of work becomes of distinctly appreciable size. In all cases, therefore, the clearance angle adopted for standard shop tools must be sufficiently large to avoid all possibility from this source of rubbing the flank of the tool against the spiral flank of the forging. The clearance angles for roughing tools in common use vary between 4 degrees and 12 degrees. We have had experience on a large scale in different shops with tools carefully ground with clearance angles of 5 degrees, 6 degrees and 8 degrees. In the case of one large machine shop which had used clearance angles ground to 8 degrees through a term of years, they finally adopted the 6 degrees clearance angle with satisfaction. For many years past our experiments have all been made with the 6 degree clearance angle, and this has been demonstrated to be amply large for our various experiments. On the other hand, a 5 degree clearance angle in practical use in a large shop has appeared to us through long continued observation to grind away the flank of the tool just below the cutting edge rather more rapidly than the 6 degrees angle. We have, therefore, adopted the 6 degrees clearance angle as our standard.

A CLEARANCE ANGLE OF FROM 9 TO 12 DEGREES SHOULD BE USED IN SHOPS IN WHICH EACH MACHINIST GRINDS HIS OWN TOOLS

339 It should be noted, however, that in shops systematized by us the cutting tools are invariably ground either on an automatic tool grinder, or by special men who are carefully taught the art of grinding and provided with suitable templets and gages, and that in this case the clearance angle for every tool is accurately made to 6 degrees.

340 In shops, however, in which each lathe or planer hand grinds his own tools, a larger clearance angle than 6 degrees should be used, say, an angle of from 9 degrees to 12 degrees, because in such shops in nine cases out of ten the workmen grind the clearance and lip angles of their tools without any gages, merely by looking at the tool and guessing at the proper angles; and much less harm will be done by grinding clearance angles considerably larger than 6 degrees than by getting them considerably smaller. It is for this reason that in most of the old style shops in which the details of shop practice are left to the judgment of the men or to the foreman, that clearance angles considerably larger than 6 degrees are generally adopted.

LIP ANGLE OF THE TOOL

341 The following are the conclusions arrived at regarding the angles at which tools should be ground:

342 (*A*) For standard tools to be used in a machine shop for cutting metals of average quality: Tools for cutting cast iron and the harder steels, beginning with a low limit of hardness, of about carbon 0.45 per cent, say, with 100,000 pounds tensile strength and 18 per cent stretch, should be ground with a clearance angle of 6 degrees, back slope 8 degrees, and side slope 14 degrees, giving a lip angle of 68 degrees. These angles are used in the tools illustrated on Folder 5, Figs. 21a and 25e. (See paragraphs 358 to 359)

343 (*B*) For cutting steels softer than, say, carbon 0.45 per cent having about 100,000 pounds tensile strength and 18 per cent stretch, tools should be ground with a clearance angle of 6 degrees, back slope of 8 degrees, side slope of 22 degrees, giving a lip angle of 61 degrees. These angles are used in tools illustrated in Folder 5, Fig. 25b. (See paragraph 361)

344 (*C*) For shops in which chilled iron is cut a lip angle of from 85 degrees to 90 degrees should be used. (See paragraph 365)

345 (*D*) In shops where work is mainly upon steel as hard or harder than tire steel, tools should be ground with a clearance angle of

6 degrees, back slope 5 degrees, side slope 9 degrees, giving a lip angle of 74 degrees. (See paragraph 360)

346 (*E*) In shops working mainly upon extremely soft steels, say, carbon 0. 10 per cent to 0. 15 per cent, it is probably economical to use tools with lip angles keener than 61 degrees. (See paragraphs 368 to 370)

347 (*F*) The most important consideration in choosing the lip angle is to make it sufficiently blunt to avoid the danger of crumbling or spalling at the cutting edge. (See paragraphs 352 to 356)

348 (*G*) Tools ground with a lip angle of about 54 degrees cut softer qualities of steel, and also cast iron, with the least pressure of the chip upon the tool. The pressure upon the tool, however, is not the most important consideration in selecting the lip angle. (See paragraphs 374 and 367)

349 (*H*) In choosing between side slope and back slope in order to grind a sufficiently acute lip angle, the following considerations, given in the order of their importance, call for a steep side slope and are opposed to a steep back slope:

a With side slope the tool can be ground many more times without weakening it; (See paragraphs 379)

b The chip runs off sideways and does not strike the tool posts or clamps. (See paragraph 380)

c The pressure of the chip tends to deflect the tool to one side, and a steep side slope tends to correct this by bringing the resultant line of pressure within the base of the tool, as explained in paragraph 382.

d Easier to feed. (See paragraphs 383 and 384)

350 (I) The following consideration calls for at least a certain amount of back slope. An absence of back slope tends to push the tool and the work apart, and therefore to cause a slightly irregular finish and a slight variation in the size of the work. (See paragraph 386)

351 (J) For conclusions as to clearance angle, see paragraph 335.

352 Before it is possible to discuss the proper lip angles for tools, two ways in which the cutting edge gives out should be described.

353 On Folder 6, Fig. 31a, is shown on an enlarged scale the manner in which the sharp end of the wedge of the tool spalls off or crumbles away, when the lip surface of the tool right at the cutting edge is subjected to great pressure. In pars. 516 to 519, later in the paper, it will be pointed out that in the case of cutting very hard metals and also in cutting all qualities of cast iron, the pressure of the chip is concentrated very close to the line of the cutting edge,

and the harder the metal to be cut and the smaller its percentage of extension, the greater will be the concentration of the pressure close to this line, and the greater will be the tendency of the cutting edge to spall off or crumble away.

354 On Folder 6, Fig. 31b, is shown another way in which the metal of the lip surface of the tool spalls off or crumbles away when the line of the cutting edge of the tool is subjected to great pressure in feeding or forcing the tool into the forging. In this case the hardness of the metal into which the tool is being fed is the chief element causing this type of injury to the cutting edge.

MOST IMPORTANT CONSIDERATION IN CHOOSING LIP ANGLE IS TO MAKE IT SUFFICIENTLY BLUNT TO AVOID DANGER OF CRUMBLING OR SPALLING OFF AT THE CUTTING EDGE

355 In deciding upon the acuteness of the lip angle of a tool the absolute necessity of guarding against the spalling or crumbling of the cutting edge from both of the foregoing causes becomes by far the most important of all considerations. In this connection the essential fact to be borne in mind is that the harder the metal to be cut, the blunter must be the lip angle of the tool. In the case of chilled iron and semi-hardened steel, for instance, the lip angle must be made from 86 degrees to 90 degrees. A smaller angle than this will cause the metal at the extreme cutting edge to spall off or crumble away (quite as much on account of the feeding pressure as from the pressure of the chip) and thus ruin the tool. As the metal to be cut grows softer, however, the lip angle can be made keener without danger of spalling, until with standard tools intended to cut the softer steels, say with a high limit for hardness of about 100,000 pounds tensile strength and 14 per cent to 18 per cent stretch, the smallest lip angle which, in our judgment, it is on the whole wise to use would seem to be about 61 degrees.

356 Dr. Nicolson with his dynamometer experiments (see Figs. 328 and 329 of his paper) has shown that with a "cutting angle" of 60 degrees, corresponding to a lip angle of 54 degrees, clearance angle 6 degrees, tools remove metal with the minimum of pressure. This is also corroborated in a general way by our observations in cutting dead soft steel, referred to in paragraphs 368 to 370. Therefore from the standpoint of pressure, with a view to taking the largest cut with a given pulling power and with the least strain upon the working parts of the lathe, this angle should be approached. And although, on the whole, the question of pressure on the tool has less weight than either the

crumbling at the cutting edge, the cutting speed, or the proper angles for obtaining the longest life and the largest number of grindings for a given tool, still it must be considered; and it is this which has led us to choose for our standard in each case THE KEENEST CUTTING ANGLE WHICH IS FREE FROM DANGER OF SPALLING.

357 As pointed out in paragraph 372, we belive that experiments would demonstrate the advisability of using still more acute lip angles for cutting dead soft steels.

358 Metals which even approach in hardness chilled iron and semi-hardened steel are but seldom met with in ordinary shop practice and, therefore, in selecting the lip angles for standard shop tools, we have divided the metals to be cut in a shop into two classes:

a cast iron and the harder classes of steel, say, beginning as a low limit for hardness with a steel of about 0.45 to 0.50 per cent carbon, 100,000 pounds tensile strength and 18 per cent stretch; and

b the softer classes of steel.

359 Our guiding principle in selecting the lip angles for the tools to be used in cutting cast iron and the harder classes of steel has been to select what we believe to be the smallest or most acute lip angle which can be safely depended upon to run without danger of spalling off at the cutting edge while cutting the harder steels ordinarily met with in machine shop practice (such as the hardest steels used in this country for car wheel tires, say of 135,000 to 140,000 pounds tensile strength, and 9 to 10 per cent of stretch, and, for instance, unannealed tool steels, or the harder of the oil hardened and annealed forgings which are used under government specifications for making large steel cannon, etc.); and after large experience in cutting metals of this quality we have concluded that it would be unsafe to use a more acute lip angle than that shown on Folder 5, Fig. 20a, namely, a lip angle of 68 degrees, with clearance angle of 6 degrees, side slope of 14 degrees and back slope of 8 degrees. We have demonstrated by repeated trials that tools with the above lip angle are safe from danger of spalling or of crumbling at the cutting edge, even when cutting tire steel, gun steel or tool steel.

360 For shops which are engaged mainly in cutting steels as hard as tire steel, we should recommend as a standard tool one having 6 degrees clearance, 5 degrees back slope and 9 degrees side slope, giving a lip angle of 74 degrees. Since for this special work the tools can be run at a high cutting speed, they can be ground in less time and they can be ground more times for each dressing in the smith shop than tools with more acute lip angles.

361 The following experiment was made in 1906 with a high speed tool of the latest and best composition. The chemical composition of the tool was that of tool No. 1 in Folder 20, Table 128.

362 Repeated trials with the same tool ground first with a clearance angle of 6 degrees, back slope of 5 degrees, and side slope of 9 degrees, giving a lip angle of 74 degrees; and afterwards with a clearance angle of 6 degrees, back slope of 8 degrees, and side slope of 14 degrees, giving a lip angle of 68 degrees. No difference was indicated in the cutting speed of these two tools when used upon the very hard forging referred to in Folder 20, Table 128.

363 It is interesting, however, to note that machinists who grind their own tools and who are accustomed to machining hard tires and metals of the classes above referred to, invariably use a blunter lip angle than our standard of 68 degrees. After making a few mistakes by grinding tools with lip angles which are too acute, they are sure to lean too far toward the safe side, and adopt lip angles which are not quite sharp enough. They are influenced in this very largely, however, by the fact pointed out in paragraph 124 that the less acute the lip angle, the easier it is and the less time it requires to grind a tool. A tool with a lip angle of 80 degrees for example, can be more easily ground than one with a lip angle of 70 degrees.

364 In those shops which work upon metals of average hardness and in which the tools are furnished to the machinists ground to the required shapes, and in which either automatic tool grinders are used or special grindstone men are employed to grind the tools, more work can be gotten out by grinding the tools to angles at least closely approximating ours than from the use of tools with blunter lip angles.

365 The reason for preferring the more acute lip angle of 68 degrees, for cutting medium hard metals to the angle of 75 degrees to 85 degrees adopted by the average machinist, is that the more acute angle removes the metal with a lower pressure on the tool (see paragraph 374); while repeated experiments made by us in cutting medium hard steels indicate that there is little if any difference in cutting speed between the 68 degrees lip angle and coarser angles. Our standard tools, therefore are capable of taking heavier cuts than the blunter tools, and in a given machine working to the limit of its pulling power, can remove rather more metal in a given time.

WHY TOOL FOR CUTTING SOFT CAST IRON SHOULD HAVE BLUNTER LIP ANGLE THAN TOOL FOR CUTTING SOFT STEEL

366 It may be a matter of surprise to some that we have adopted a lip angle of 68 degrees for cutting the softer grades of cast iron, while

we recommend a lip angle of 61 degrees for the softer steels. It is one of the strange anomalies met with in so many of the elements of this art, however, that if we experiment with a very soft cast iron, on the one hand, and a very soft steel, on the other—the standard cutting speeds of which are each, say, 150 feet per minute with a $\frac{3}{16}$ inch depth of cut and $\frac{1}{16}$ inch feed—in the case of the soft steel the highest speed can be obtained only with a cutting edge at least as keen as 61 degrees, and we believe even keener, while the lip angle corresponding to the highest cutting speed with soft cast iron is 68 degrees or even blunter. The following experiments were carefully made and have since been verified by repeated trials.

367 In 1894 before the discovery of high speed cutting tools, the standard speed for cutting soft cast iron was determined for each of two sets of tools, one set having a lip angle of 61 degrees and the other 68 degrees. These tools were made from tempered carbon steel of $\frac{1}{4}$ inches by $1\frac{3}{4}$ inch section, having the curve of the cutting edge as shown in standard, Folder 5, Fig. 24. One set was ground with 6 degrees clearance angle, 8 degrees back slope, and 14 degrees side slope, thus giving a lip angle of 68 degrees. The other set was ground with a clearance angle of 6 degrees back slope of 8 degrees, and side slope of 22 degrees, thus giving a lip angle of 61 degrees. These two sets of tools were successively run on a carefully standardized test piece of soft cast iron of about 24 inches diameter. The standard ruining speed of the 68 degrees angle was 67 feet, while the standard ruining speed of the 61 degrees lip angle was $65\frac{1}{2}$ feet; thus in cutting soft cast iron, changing the lip angle from 68 to 61 degrees reduced the cutting speed from 67 to $65\frac{1}{2}$ feet, a loss of 2.3 per cent in speed.

368 On the other hand, the following result was obtained repeatedly in experiments made in 1900 upon a carefully standardized test forging made of soft steel, whose chemical composition and physical properties were about:

Carbon	0.105 per cent
Manganese	0.25 per cent
Silicon	0.008 per cent
Sulphur	0.04 per cent
Phosphorus	0.008 per cent
Chromium	0.047 per cent
Tensile Strength	48,000 pounds
Elastic Limit	24,500 pounds
Extension	39 per cent
Contraction of Area	62 per cent

Taylor-White treated tools of the chemical composition of tool steel

No. 27 on Folder 21, Table 139, were used. Body of the tool, $\frac{7}{8}$ by $1\frac{3}{8}$ inch, curve of the cutting edge, shown in Folder 5, Fig. 24, with a clearance angle of 6 degrees, back slope 12 degrees, side slope 18 degrees, giving a lip angle of about 61 degrees. The standard ruining speed with a $\frac{3}{16}$ inch depth of cut and a $\frac{1}{16}$ inch feed was 150 feet per minute; tools in other respects exactly like these, except that the back slope was 8 degrees and the side slope 14 degrees (giving a lip angle of 68 degrees), showed in repeated trials a ruining speed of from 125 to 130 feet.

369 The effect of changing the lip angle from 68 to 61 was to increase the cutting speed from 125 to 150 feet, a gain of 20 per cent. Thus a more acute cutting angle used on a tool for cutting soft steel produces just the opposite effect from that produced in cutting equally soft cast iron.

370 The lip angle of 68 degrees used in cutting soft steel, when tried at the high speed of 150 feet, caused the chip to be much more distorted or upset, and thickened, and after running a short time at this speed, the chip began to stick to the lip surface of the tool almost as though it were welded. With the more acute angle of 61 degrees this bunching up of the chip and welding did not occur. It was also evident that when the chip began to weld to the lip of the 68 degree tool, the power required to cut the metal was so greatly increased as in a number of cases to entirely stall or slow down the lathe, whereas with the 61 degrees lip angle, the lathe was never slowed down in the least. At slower cutting speeds it was not noticeable that the 68 degrees tool consumed any more power than the 61 degrees tool.

371 It would be interesting to repeat this experiment at the very high speed with a dynamometer, carefully measuring the pressure of the chip on the tool.

372 The writer believes that it would be profitable to experiment with more acute lip angles than 61 degrees in cutting dead soft steel such as above referred to, containing about 0.10 per cent carbon, and of 48,000 pounds tensile strength, which approximates to wrought iron. It may be that with this extremely soft steel still higher cutting speeds could be obtained with more acute angles, in which case it would be advisable of course to make special tools for cutting this quality of metal in shops where large amounts of it are used. However, a trial of this sort would not modify our selection of 61 degrees for the standard angle for cutting the ordinary softer steels met with in the average machine shop, because as explained above, our standard shop tools for cutting the softer steels are intended for use in cutting metals with an upper limit of hardness of about carbon 0.45 to 0.50, say,

100,000 pounds tensile strength, 18 per cent of stretch or thereabouts, and if a more acute lip angle than, say, 61 degrees were used in cutting steel of this hardness, there would be danger of the cutting edge crumbling away or spalling off.

THEORY AS TO WHY AN ACUTE LIP ANGLE PRODUCES A HIGHER SPEED FOR CUTTING SOFT STEEL AND A SLOWER SPEED FOR SOFT CAST IRON

373 In all matters pertaining to this art a theoretical explanation of the various phenomena is of less importance than a clear knowledge of the facts. However, it may still be of interest, at least, to present our theory as to the opposite effects of an acute lip angle in the case of soft cast iron and soft steel.

374 Dr. Nicolson in his dynamometer experiments has demonstrated the fact that tools ground with a "cutting angle of 60 degrees" which corresponds to a "lip angle of 54 degrees" work with a smaller total pressure upon the tool than tools whose cutting angles are either larger or smaller than 54 degrees, the metals upon which he experimented being as follows: Medium cast iron, which with a $\frac{3}{16}$ inch depth of cut and a $\frac{1}{16}$ inch feed having a standard speed of 49 feet per minute; and steel 60,000 pounds tensile strength and 26 per cent extension, having a standard speed of 111 feet per minute with a $\frac{3}{16}$ inch depth of cut and $\frac{1}{16}$ inch feed. His experiments, however, show that although tools of these angles cut with less pressure, yet tools with larger angles can be run at higher cutting speeds. This confirms our experiments on cast iron as cited above in paragraph 367. The reason for this phenomenon appears to be as follows:

375 First, the amount of heat generated by the friction of the chip is doubtless closely proportional to the pressure of the chip upon the tool. Therefore, with the 54 degrees cutting angle and its lower pressure there will be less heat generated than with the larger cutting angles. On the other hand, the heat is carried away from the cutting edge mostly through the metal of the tool itself (very little heat being radiated into the air); and the more acute the angle of the tool, the smaller will be the cross-section of the wedge shaped metal of the tool close to the cutting edge, so that the blunter angled tools will have also a larger section of metal for carrying away the heat. In addition to this, and of greater importance in our judgment, is the fact that in cutting cast iron the pressure of the chip comes very close to the cutting edge of the tool, as explained in paragraph 523, and the more acute its angle, the more will a trifling amount of wear or

damage affect the cutting edge. These two causes working together operate to enable the blunter cutting edge to run at higher speeds in cutting cast iron. On the other hand, as pointed out in paragraphs 170 and 516, the pressure of the chip in cutting dead soft steel comes at a considerable distance from the cutting edge, so that in this case the more delicate edge of the acute angled tool is further removed from the source of heat and also subject to much less abrasive wear than in cutting cast iron; and the cross-section of the tool beneath the center of pressure of the chip is much larger. Therefore, in the case of very soft steel we have exactly the reverse effect, as described in paragraph 368, namely, the more acute their lip angles down to 61 degrees (the low limit experimented with by us), the higher the cutting speeds at which tools can be run.

WHY TOOLS SHOULD BE GROUND WITH GREATER SIDE SLOPE THAN BACK SLOPE

376 We have endeavored above to make it clear that the paramount consideration affecting the choice of the lip angle for standard tools has been the avoidance of the danger of spalling or crumbling at the cutting edge. Having chosen a lip angle which is sufficiently blunt to avoid danger from this cause, it must still be decided whether this angle shall be produced, say, altogether by side slope or altogether by back slope, or by a combination of side slope and back slope; and in settling this question there are several important, and, as usual, conflicting considerations. These may be divided into the following groups, which are given in the order of their importance:

a Ease and cheapness of grinding and the effect of repeated grindings upon the strength and life of the tool;

b Guiding the chip in the proper direction for convenience in operating;

c The effect of pressures produced by side slope and back slope upon the tendency of the tool to gouge or plunge either forward or sideways;

d The power required to feed.

377 In the following brackets are grouped these several considerations, in the order of their relative importance, as they affect favorably or unfavorably the adoption of a steep side slope:

IN FAVOR OF STEEP SIDE SLOPE

a With side slope tool can be ground many more times without weakening it;

b Chip runs off sideways and does not strike tool post or clamps;

c Less tendency to force and deflect the tool to one side as it tends to bring resultant line of pressure within base of the tool, as explained in paragraph 382;

d Easier to feed.

AGAINST STEEP SIDE SLOPE

a Danger of gouging or plunging into the work greater.

378 And in the following brackets are also grouped the same considerations as they affect favorably or unfavorably a steep back slope:

IN FAVOR OF STEEP BACK SLOPE

a Does not push tool and work away from one another.

AGAINST STEEP BACK SLOPE

a Grinds down into body of tool and weakens tool and allows fewer grindings for given height of tool;

b In case of gouging, the work is more apt to be spoiled through tool plunging forward as it does with steep back slope than if it plunges sideways as it does with steep side slope;

c Runs chip directly back against tool, tool post or clamp;

d Harder to feed.

SIDE SLOPE AND BACK SLOPE AS AFFECTED BY THE GRINDING

379 On Folder 7, Figs. 39a and 39b, we show the side view of two tools, in both of which views the lip angle of the tool is 61 degrees. In the case of Folder 7, Fig. 39b, the lip angle is attained entirely through back slope while in Folder 7, Fig. 39b, and Folder 5, Fig. 20b (standard tool for cutting soft steels), there is 8 degrees of back slope and 22 degrees of side slope. The cutting edges of both of these tools are of the same height. An inspection of the drawings will show, however, that the tool with all back slope can be ground but comparatively few times before the corner of the grindstone will begin to cut away the body of the tool, thus weakening it, and allowing a comparatively small number of grindings before the tool is redressed, while at the same time making the grinding much more expensive, as explained in paragraphs 435 to 439.

SIDE SLOPE AND BACK SLOPE AS THEY AFFECT THE DIRECTION OF THE CHIP

380 With the modern high speeds used in cutting steel the disposition of the chip becomes a matter of no small moment, and in many cases it is absolutely necessary in designing the tool to provide against the jamming of the chip either between a portion of the tool itself and the lip surface of the tool, or between the nose of the tool and the clamps or tool post which hold it.

381 It is evident that a steep back slope tends to throw the chip either directly against the tool or against the tool post or clamps, while a steep side slope guides the chip off to one side, and this therefore becomes one of the most important reasons for adopting a steep side slope.

THE TENDENCY OF THE PRESSURE OF THE CHIP TO BEND THE TOOL TO ONE SIDE

382 In pars. 417 to 425, relating to the dimensions of the steel to be used in the body of the tool, will be seen the desirability of keeping the resultant line of pressure of the chip upon the tool within or as near as possible to the base of the tool. Dr. Nicolson's experiments (Fig. 336 of his paper) show that the side pressure of the chip upon the tool diminishes as the cutting angle becomes more acute and reaches a minimum with an angle of 60 degrees. Therefore a steep side slope will tend to keep the resultant line of pressure within the base of the tool.

THE EFFECT OF SIDE SLOPE AND BACK SLOPE UPON THE POWER REQUIRED TO FEED THE TOOL

383 The diagram in Fig. 336 in Dr. Nicolson's paper also indicates the desirability of a steep side slope even to the extent of 30 degrees in diminishing the power required to feed.

384 A tool ground with a slope of 30 degrees offers a resistance to feeding of but 1 per cent to 10 per cent while a tool ground with a 15 degrees slope meets with a feeding resistance equal to from 12 per cent to 20 per cent of the total pressure on the tool.

385 For further discussion of feeding resistance, see paragraph 581.

BACK SLOPE NEEDED TO SECURE BETTER FINISH AND GREATER ACCURACY IN SIZE

386 A study of all of the above elements would lead to the conclusion that tools should be designed with all side slope and no back

slope. There is, however, one element which makes it desirable to have a certain amount of back slope; namely, the fact that a steep back slope diminishes the tendency of the chip to push the tool and the work away from one another, and it is evident that the greater the pressure tending to force the tool and the work apart, the greater will be the irregularity in the finish left by the nose of the tool upon the work. This irregularity both in size and finish is particularly noticeable in those cases in which the tool and its supports are not especially rigid, and in which the depth of the cut varies from one part of the forging to another; and also when the surface of the forging is more or less eccentric or uneven owing to the irregularities left by the hammer in forging.

387 In paragraph 217 special attention has been called to the necessity for great rigidity in all parts of the lathe to be used in experimenting. There are a few important elements, however, which can only be studied through the use of a lathe in which the supports for the tool are more or less yielding, and even somewhat loose rather than rigid. These elements are:

a the tendency of the tool to gouge or plunge into the work; and

b the forcing of the tool and the work apart.

388 It is evident that the effect of the acuteness of the angle of slope of the tool is directly opposite in these two cases. The more acute the angle of slope, the greater the tendency to gouge, and the less the tendency to push the work and the tool apart. It may be said that in well managed machine shops the tool supports will be properly adjusted so as to avoid any lost motion or looseness, and that therefore the tendency to gouge from this cause should not be considered. The fact is, however, that we are dealing with shops as they are, and even in many of the best shops, machines will be found whose tool supports are entirely too springy and more or less less worn or out of proper adjustment. We have made repeated careful experiments with lathes having springy tool supports and with more or less lost motion, and in such machines, providing the tool is fastened tight in the tool post, we have found that the tools ground to our standard angles, shown on Folder 5, Figs. 20a and 20b, very rarely gouge or plunge forward or sideways seriously. The danger of plunging forward, however, has been one of the reasons influencing the adoption of a back slope as small as 8 degrees.

389 The tendency of the tool and work to push apart, on the other hand, is very marked with tools designed with all side slope and no back slope. A series of experiments was tried with a set of tools,

in the one case having 6 degrees clearance, 8 degrees back slope, 14 degrees side slope; and in the other case, a set having 6 degrees clearance, a back slope of minus 5 degrees, or more properly a forward slope of 5 degrees; and a side slope of 25 degrees. The lip angle of the first of these sets being 68 degrees, while the lip angle of the second was about the same. One of the principal reasons for comparing these types of tools was that the tool when ground with 5 degrees front slope makes what is known as a shearing cut and that a shearing cut has the special advantage of leaving a smoother finish.

390 The standard speeds of these two tools were found through accurate experiments to be practically the same, there being less than 1 per cent difference between the two in favor of the 8 degrees back slope. With these tools, however, even when used in a lathe with a comparatively rigid and a tight and well adjusted tool support, there was a most noticeable difference in the tendency to push the tool and the work apart. With heavy cuts a much smoother and better finish was left by the tool with the 8 degrees back slope in spite of the shearing effect of the other tool; and it was evident to all of those who watched the experiment that the tool with back slope was greatly to be preferred to the other. It may add weight to understand that this particular experiment was made at the request of the superintendent and foreman of a large machine shop in which tools ground with the 5 degrees front slope had formerly been standard. These men, however, were completely convinced through watching the two types of tools working under exactly uniform conditions.

FORGING AND GRINDING TOOLS

ON THE SHAPE OF TOOLS AS AFFECTED BY GRINDING AND FORGING

391 The following are the important conclusions arrived at upon this subject:

392 (A) The shapes into which tools are dressed and the ordinary methods of dressing them are highly uneconomical, mainly because they can be ground only a few times before requiring redressing. (See paragraphs 431 to 441)

393 (B) The tool steel from which the tool is to be forged should be one and one-half times as deep as it is wide. (See paragraphs 420) The standard length for tools will be found in Folder 6, Table 27. (See paragraph 428)

394 (C) To avoid the tendency of the tool to upset in the tool

post under pressure of the cut, the cutting edge and the nose of the tool should be set well over to one side of the tool. (See paragraph 422)

395 (D) Tool builders should design lathes, boring mills, etc., with their tool posts set down lower than is customary below the center of the work. (See paragraph 426)

396 (E) In choosing the shape for dressing a tool, that shape should be given the preference in which the largest amount of work can be done for the smallest combined cost of forging and grinding.

397 (F) Forging is much more expensive than grinding, therefore the tool should be designed so that it can be ground:

a the greatest number of times with a single dressing; and

b with the smallest cost each time it is ground. (See paragraph 431)

398 (G) Best method of dressing a tool is to turn its end up high above the body of the tool. (See paragraph 442) Tools can be entirely dressed by this means in two heats. For detailed steps in forging a tool by this method see:

a heating (see paragraphs 447 to 460);

b bending (see paragraph 450);

c drawing down the heel (see paragraph 454);

d shaping with the chisel (see paragraph 456);

e cutting correct height and lip angle (see paragraph 458)

f setting over to one side (see paragraph 459).

399 (H) Importance of carefully heating the tool for dressing. (see paragraphs 447 to 449);

400 (J) Fire or heat cracks in tools are due to the following causes:

a Seams or internal cracks in bar of tool steel. (See paragraph 461);

b Nicking and breaking the bar of tool steel while it is cold. (See paragraphs 445 and 463);

c Failing to turn the tool over and over while heating it for forging. (See paragraph 464);

d Too rapid heating, particularly at the start, in a hot fire. (See paragraphs 466 to 468);

401 (K) It is of great importance to properly adjust the relative amount of work to be done in the smith shop and on the grinding machine in making the tool.

a Too much work is generally done in dressing tools to exact shape in the smith shop, particularly when automatic grinding machines are used. (See paragraph 470)

b A limit gage should be used by the smith to properly regulate the proportion of smith work and grinding work in making the tool. (See paragraph 471)

ON GRINDING TOOLS

02 The following are the important conclusions arrived at with rence to grinding tools:

03 (A) More tools are ruined in every machine shop THROUGH R HEATING IN GRINDING than from any other cause. (See agraphs 473 and 1016)

04 (B) The most important consideration is how to grind tools idly without overheating them. (See paragraph 473)

05 (C) To avoid overheating, a stream of water amounting to gallons per minute for the largest sized tools, should be thrown ferably at a slow velocity, directly on the nose of the tool where in contact with the emery wheel. (See paragraph 473)

06 (D) To avoid overheating where tools are ground by hand or h an automatic tool grinder, the surface of the tool should never be wed to fit closely against the surface of the grindstone. To pre- t this, tools should be constantly moved or wobbled about during operation of grinding. (See paragraph 481)

07 (E) To lessen the danger of overheating on the emery wheel l to promote rapid grinding, tools should be dressed so as to leave smith shop with a clearance angle of about 20 degrees, while 6 de- es only is needed for cutting. (See paragraph 474)

08 (F) Flat surfaces upon tools tend far more than curved sur- es to heat tools in grinding. (See paragraph 481)

09 (G) Tools with keen lip angles (*i.e.*, steel side slopes) are ch more expensive to grind than blunt lip angles. (See paragraph 8)

10 (H) It is economical to use an automatic tool grinding ma- ine even in a small shop. (See paragraph 486)

11 (J) There is little economy in an automatic grinder for any op unless standard shapes have been adopted for tools, and a large pply of tools is kept always on hand in a first-class tool room so that ols of exactly the same shape can be ground in quite large batches or ta. (See paragraph 488)

12 (K) Corundum wheels made of a mixture of grit size No. 24 d size No. 30 are the most satisfactory for grinding ordinary shop ols. (See parargaph 483)

14 (L) In grinding flat surfaces skillful hand grinders invariably

keep the tool wobbling about on the face of the grindstone in order to avoid heating. (See paragraph 481)

ON THE SIZE AND PROPORTION OF THE BODY OF THE TOOL

415 Twenty-five years ago it was perhaps the more general practice in this country to make the cross-section of the body of lathe and planer tools square, and this practice still generally prevails in England and upon the Continent. In fact, in the report of the Manchester experiments, referred to in paragraph 77, of this paper, in which the tools of eight of the leading engineering establishments were placed in competition, all of the tools illustrated have square shanks. Mr. James M. Gledhill also, in his admirable paper, on "The Development and Use of High Speed Tool Steel," read before the Iron and Steel Institute in 1904, refers to tools with square shanks as being the standard in use in the works of Armstrong, Whitworth & Co. It may be said, however, that the more general practice in this country at the present time is to make the depth of the body of the tool considerably greater than its width.

416 In choosing the proportion of the height of the shank to its depth, the effect of two forces must be considered—the downward pressure upon the nose of the tool, due to cutting the chip; and the side pressure at right angles to the tool due partly to the feeding resistance, and partly to the direction in which the chip moves across the lip surface.

417 Dr. Nicolson, in his experiments, has shown that in the great majority of cases the side pressure upon the tool does not exceed 20 per cent of the downward pressure; and that more frequently the side pressure is even a smaller percentage of the vertical pressure. On the other hand, tools when properly designed and properly placed in the tool post are supported in the majority of cases almost directly beneath the cutting edge, thus directly resisting the downward pressure upon the tool, and placing it mainly under compression, and so greatly diminishing the heavy downward transverse bending and breaking strains. If, then, tools were always set in their most advantageous position in the tool post, the practice of using steel of square cross-section might not be far wrong. However, in both lathe and planer work it is often necessary to set the tool with considerable overhang beyond the tool support, and in these instances it is evident that the depth of the tool should be considerably in excess of the width; because it must be borne in mind that the transverse strength of a rectangular bar under vertical pressure increases with the square of its depth, while it increases only in direct proportion to the width.

418 It is manifestly of great importance to have the tools as light as possible consistent with their strength both for ease of handling, in setting the tool in and removing it from its tool post, in grinding and in dressing; and a much lighter tool of equal strength and stiffness can be used when the height exceeds the width than when the cross-section is square.

419 For the above reasons some of the large machine shops in this country have adopted a proportion of 2 in height to 1 in width for the cross-section of their standard tools.

420 However, owing to the desirability of turning the noses of tools high above the top surface of the body of the tool for economy in grinding and dressing, as explained in paragraphs 431 and 442 and also owing to the design of the tool posts of the greater part of the machines in this country (referred to later in paragraph 426,) it is, in the judgment of the writer, unwise to adopt a height as great as 2 to 1 for the body of the tool. After practical trial on a large scale and close observation of several different proportions, we have adopted as standard the section of $1\frac{1}{2}$ in height to 1 in width for the body of the tool.

421 There is one other element, however, which requires consideration, namely, the tendency to upset the tool or turn it over on to its side. It is clear that the higher the nose of the tool is raised above the point of support and the narrower the width of the tool, the greater becomes the tendency to upset the tool sideways; and that in many respects what may be called the English, Continental and old American standards of square section tools with cutting edges close to the level of the top of the tool, appear to offer far greater stability than our standard.

IMPORTANCE OF BENDING THE NOSE OF TOOLS OVER TO ONE SIDE TO AVOID DANGER OF UPSETTING

422 The tendency to upset may be mathematically defined as having the resultant line or direction of the combined vertical cutting forces and lateral feeding forces fall outside of the supporting base of the tool.

423 On Folder 2, Figs. 14, 15 and 16 we have shown three views of tools. Fig. 14 represents the English type of tool, Fig. 15 the American type, as perhaps in more common use, and Fig. 16 our standard tool. In each case the heavy line drawn from the cutting edge of the tool downward and to the left indicates the resultant line of pressure upon the nose of the tool. It will be observed that in the case of the

English type of square sectioned body the resultant line of pressure falls well within the base of the tool, while in the average American type the resultant line comes close to the outer edge of the base of the tool. With our standard tool, the resultant line of pressure again falls close to the center of the base of the tool. This has been our principal reason for bending or setting the nose or cutting edge of all of our tools far over to one side of the center line of the shank, as explained in paragraph 459 and as seen in all of the views of our standard tools. Thus it will be noted that our standard tool has all of the advantages of the American type, together with the additional stability of the English type.

424 This plan of setting the tool over to one side has also great advantages in cheapening the grinding and in diminishing the danger of overheating the cutting edge in grinding as referred to in paragraph 474.

425 The serious mistake then in the design of the average American type of body has been that of following the English and Continental practice in keeping the curve of the cutting edge symmetrical or central with the body of the tool, instead of moving it over so as to be well outside of the base of the tool.

IMPORTANCE OF LOWERING TOOL SUPPORTS IN DESIGNING MACHINE TOOLS

426 We attach so much importance to raising the nose of the tool above its top surface and at the same time having the section of the body of the tool deeper than its width, that we would especially call the attention of machine tool builders to the desirability of designing their tool supports in lathes, boring mills, etc., further below the centers than is customary. When preparing for the best shop standards in reorganizing the management of machine shops, it has become our custom to systematically go over all of the machine tools and lower the tool rests to as great an extent as is practicable. Fortunately this in many cases entails but a small expense. However, in other cases it has been found desirable and economical to re-design the cross slides of many lathes so as to accomplish this object.

THE LENGTH OF THE SHANKS OF CUTTING TOOLS

427 In choosing the proper lengths for cutting tools, we again find two conflicting considerations:

428 (A) It requires a certain very considerable length for the shank of each sized tool in order to fasten or clamp it in its tool post.

When the tool becomes shorter than this minimum, it must be thrown away, thus wasting costly metal, particularly in the case of the modern high speed tools.

429 (B) On the other hand, the longer the body of the tool, the more awkward and the slower become all of the operations in handling the tool, beginning with the dressing and followed by the grinding, storing, handling in the tool room, and setting and adjusting in the machine.

430 We know of no definite, clear cut method of comparing the relative loss in handling long and heavy tools with that of the waste of the tool steel, so that the adoption of standard lengths for dressing tools of various sizes has been largely a matter of "rule of thumb" judgment on our part. We give, however, on Folder 6, Table 27, the length of tools, which we have adopted corresponding to different sized bodies.

TOOLS SHOULD BE DESIGNED SO THAT LARGEST AMOUNT OF WORK CAN BE DONE FOR SMALLEST COMBINED COST OF FORGING AND GRINDING

431 In adopting the general shape or conformation of a tool (we do not here refer to the curve of the cutting edge), the most important consideration is that of selecting a shape with which the largest amount of work can be done for the smallest COMBINED COST OF FORGING OR DRESSING AND GRINDING, and the dressing is much the more expensive of these two operations. It is, therefore, of paramount importance to so design the tool that it can be ground:

a the greatest number of times with a single dressing;
b with the smallest cost each time it is ground.

432 As indicated in paragraph 201, modern high speed tools when run at economical speeds are injured much more upon the lip surface than upon the clearance flank. Therefore, at each grinding a larger amount of metal must be ground away from the lip surface than from the clearance flank; and yet in many cases the clearance flank will be more or less injured (rubbed or scraped away) below the cutting edge, and it therefore becomes necessary, for maximum economy, in practical use, to grind roughing tools both upon their lip and their clearance surfaces.

433 On Folder 3, Fig. 17e, is shown the typical wear on a tool which has been run at an economical speed. This tool has been cuttered out on the lip surface and also slightly rubbed away on its clearance flank. It is evident that if it were ground on the lip sur-

face alone a considerable amount of the metal would be wasted before the cutting edge of the tool could be completely resharpened.

434 On the other hand, it is clear that if the tool were to be ground on its clearance flank alone, a much larger amount of metal must be ground off before entirely restoring the line of the cutting edge. This shows that for economy tools must be ground both upon their lip and clearance surfaces.

335 In many shops the practice still prevails of merely cutting a piece of the proper length from a bar of steel and grinding the curve or outline of the cutting edge at the same level as the top of the tool, as shown on Folder 7, Figs. 36 and 37. This entails the minimum cost for dressing, but makes the grinding very expensive, since the lip surface must be ground down into the solid bar of steel, thus bringing the corner of the grindstone or emery wheel at once into action and keeping it continually at work. This quickly rounds over the corner of the stone, and necessitates its frequent truing up, thus increasing the cost of grinding both owing to the waste of the stone and the time required to keep it in order; and it also leaves the face of the grindstone high in the center most of the time, and unfit for accurate work.

436 As far as possible, then, the shape of standard cutting tools should be such as to call for little or no grinding in which the corner of the emery wheel does much work. With the type of tool illustrated on Folder 7, Fig. 36, also, comparatively few grindings will make a deep depression in the body of the tool, as shown on Folder 7, Fig. 38, and this depression will of course be greater the steeper the back slope of the lip surface of the tool.

437 To avoid these difficulties, perhaps the larger number of well managed machine shops in this country have adopted a type for dressing their tools in which the front of the tool is forged slightly above the level of the tool, as shown on Folder 7, Figs. 37 and 38. This type of tool dressing is done in each of the following ways:

438 (A) By laying the tool on its side and slightly flattening its nose by striking it with a sledge, thus narrowing the nose of the tool, and at the same time raising it slightly above the level of the top of the tool, as shown on Folder 7, Fig. 38.

439 (B) By cutting off the clearance flank of the tool at a larger angle than is demanded for clearance and then slightly turning up the cutting edge of the tool through sledging upon the clearance flank while the tool is held upon the edge of the anvil with its shank below the level of the anvil. This type of dressing is shown on Folder 7, Fig. 37.

440 The objection to both of these types is that the tools require

redressing after being ground a comparatively small number of times, and that when redressed in many cases the whole nose of the tool is cut off and thrown away. (This waste of metal, however, is of much less consequence than the frequency of dressing.)

441 It will also be observed that with the first of these types of tool dressing the tendency is to make the nose of the tool too thin, that is, having too small a radius of curvature, and thus to furnish a tool which must be run at too slow cutting speeds, as indicated in paragraph 326. It will be noted that both of these types of tool dressing call for at least one heating of the tool and that in most cases the tool is actually heated twice.

THE BEST METHOD OF FORGING A TOOL IS TO BEND OR TURN UP ITS END

442 Undoubtedly one of the most economical shapes for tools, when both dressing and grinding costs are considered, is that shown in our standard tools, Folder 5, Figs. 25a to 25e.

443 In examining these tools it will be noted that in the 1½ inch tool, for instance, the cutting edge is $1\frac{3}{16}$ inches above the top of the body, and if we assume that $\frac{1}{32}$ of an inch of metal ground off from the height of the tool will be sufficient to sharpen the cutting edge on an average, it is evident that a tool of this shape can be ground 24 times before the corner of the emery wheel begins to cut into the body of the tool. If after this we continue to grind the tool, there will still remain as many grindings on this tool as upon tool, Folder 7, Figs. 38 or 39b, before the wheel shall have ground down into the body of the tool for a sufficient depth to weaken it. Thus it is clear that our standard tool has a shape which permits it to be reground from three to five times as many times as the ordinary shape shown on Folder 7, Fig. 38.

444 In dressing these tools the end of the piece of steel to be made into the tool is bent or turned up by sledging it down across the corner of the anvil. Folder 1 and Folder 2 illustrate one method of doing this work. It is of interest to note that after the steel from which the tool is made has been cut to the required length and properly marked for identification, these tools up to and including tool steel of 1 inch x 1½ inch can be completely dressed by a good smith and his helper ready for grinding in two heats, providing a small steam hammer with plain flat dies is available for striking the tool a few blows at the proper time; also that without a steam hammer, each tool can be readily dressed with three heats by a smith and one helper or in two heats by a smith and two helpers, the two helpers being required for only a part of a minute.

IT IS A BAD PRACTICE TO NICK THE BAR OF TOOL STEEL AND BREAK IT OFF COLD

445 The practice of nicking the bar of tool steel with a cold chisel at points corresponding to the proper length of the tool, and then breaking it where nicked by a blow of the sledge on the anvil, is on the whole unwise, as not unfrequently almost invisible cracks are started which may only fully develop after the tool is in use. In cutting to length with a "hot chisel" a low heat is sufficient and the same heat can be used for stamping the rear end of the tool for identification.

446 The following are the steps to be taken in forging the tool after it has been cut to length from the bar.

HEATING THE TOOL

447 (A) Heat the tool rather slowly so as to insure uniform heating to the center of the bar, turning it over several times while in the blacksmith's fire. The proper heat with the modern low carbon, high tungsten and chromium steels is as high a heat as can be used without causing the steel to disintegrate or fly to pieces when struck with the sledge. Contrary to all former laws and traditions in heating tool steel, this type of steel is not injured by heating beyond a cherry red in dressing, providing the tool is finally to be heated to the high melting point according to the Taylor-White process. The proper dressing heat varies according to the chemical composition of the tool steel, but is in most cases from a yellow to a light yellow heat corresponding to a temperature of 1800 degrees F. to 1900 degrees F.

448 In the case of a tool 1 inch in the body this yellow heat should extend 5½ inches back from its point and in the following description the dimensions given will be understood to refer to a tool of this size.

449 When several tools of the same shape are to be dressed at the same time, it is best to heat them slowly in lots of, say, four to six tools at a time; the part of the tools to be heated being brought closer and closer to the hot portion of the fire as they are gradually warmed up, while the one particular tool which is to be forged next is kept directly over the hottest part. A clear coke fire, made and kept sufficiently deep to measurably prevent the blast from coming directly in contact with the tool is, on the whole, preferable to the ordinary soft coal fire used by blacksmiths. This is true, however, only because it is easier to get a uniform fire with coke as the fuel than when coal

is used in a blacksmith's fire. The experiments described in paragraph 1010 show clearly that if sufficient care is used, a first-class soft coal fire oxidizes, and therefore injures, the tools less than a first-class coke fire.

BENDING OR TURNING UP THE NOSE OF THE TOOL

450 (B) Clamp the tool down hard on to the top of the anvil, as shown on Folder 1, Fig. 1, by drawing down the clamp C by means of the wedge W, the upper edge of which presses against the lower side of the anvil, and the lower edge against the end of the slot made in the shank of the clamp C, which passes down through a square hole in the anvil and projects below the underside of the same. The tool is clamped so that $2\frac{3}{4}$ inches of its end project beyond the edge of the anvil.

451 (C) The blacksmith and his helper each working with a sledge bend the heated end of the tool down into the position shown on Folder 1, Fig. 2. (The exact shape of tool as thus bent over is shown on Folder 2, Fig. 7)

452 A gage similar to that shown on Folder 1, Fig. 6, should be mounted close to the blacksmith's anvil, so that he can readily test the bending of the tool to secure the proper clearance angle. This gage consists of a small surface plate with a hole drilled near one corner, into which are fitted a series of cones turned to different angles, corresponding to the various shapes into which the tools are to be bent. The tool without removing the tongs is placed with its bottom surface on the surface plate and the clearance surface against the tapered cone, where at a glance the blacksmith can see whether he has bent it to the correct angle.

453 A similar clearance gage should also be mounted close to the tool grinder so that the clearance angle called for in grinding can be quickly and accurately measured by the operator.

DRAWING DOWN THE HEEL OF THE TOOL TO SECURE GOOD BEARING

454 (D) The wedge W of clamp C is then loosened with a hammer, and the tool quickly removed to the steam hammer with flat dies, where the curved portion at the heel of the tool is placed, as shown on Folder 1, Fig. 3, upon the edge of the die, and drawn down with a few blows of the hammer so as to flatten it into a wedge shape. This flattening spreads the metal out laterally until what was a rounding corner becomes almost a right angle; thus extending the flat surface of the bottom of the tool further forward, so as to furnish a support

almost under the cutting edge. (The tool in this condition is shown on Folder 2, Fig. 3)

455 In case no small steam hammer is available, the heel of the tool is flattened in a similar manner by sledging upon the blacksmith's anvil.

CUTTING OFF CORNERS OF NOSE OF TOOL SO AS TO SAVE WORK IN GRINDING

456 (E) The tool is placed upon the edge of the anvil, as shown on Folder 1, Fig. 5, and its two corners are cut off with a chisel so as to make its nose approximate to the proper curve. The bottom of the heel of the tool is also trimmed off, if necessary, so as to make it flush with the bottom of the tool. The height is then marked with soapstone or a nick of the chisel upon the nose of the tool for cutting to the proper lip angle, and the tool is returned to the fire for its second heat.

457 It should be noted that operations B, C, D and E are all done with a single heat. If, however, at any stage in the process through lack of skill or unusual delay the tool is cooled to below a light cherry red, corresponding to a heat of 1550 degrees F., no further forging should be done without reheating.

CUTTING TO CORRECT HEIGHT AND LIP ANGLE

458 (F) After slowly and thoroughly reheating the tool, the upper portion of the nose is cut, as shown on Folder 1, Fig. 4, to the proper lip angle, care being taken to secure both the correct angle and height called for. The use of a specially designed hot chisel or set, as shown on Folder 1, Fig. 4, will help the blacksmith in this operation.

BENDING OR SETTING THE NOSE OF THE TOOL OVER TO ONE SIDE AND TRUING UP THE WHOLE TOOL

459 (G) The whole nose of the tool is then bent and set over sidewise through the use of a flatter, as shown on Folder 2, Fig. 12.

460 (H) The tool should be carefully straightened on the anvil so as to have as nearly as possible a true bearing upon its bottom surface. This bearing should extend all the way from the front to at least halfway back on the tool. A surface plate should be provided close to the blacksmith's anvil for testing the accuracy of this operation. The importance of having this bottom surface true is not ordinarily appreciated. The tool should bear at all points along its bottom surface,

at its forward end, directly underneath the cutting edge, in order to avoid chatter or breaking through too much overhang; and also directly beneath the clamp to avoid either bending or breaking at this point.

FIRE OR HEAT CRACKS IN TOOLS COME FROM FOUR PRINCIPAL CAUSES

461 (A) Seams or internal cracks in the bar of tool steel, caused mainly by imperfections in the ingot or by too rapid or uneven heating in hammering the bar.

462 Blacksmiths are prone to attribute all cracks in their tools to the maker of the tool steel. It is our observation, however, that nine-tenths of the cracks in tools are due to bad treatment in the smith shop rather than to imperfections in the bar.

463 (B) The second cause for cracking is breaking the bar while cold, as referred to in paragraph 445.

464 (C) The third cause is heating the bar unevenly by keeping it in the same position in the fire throughout the time of heating.

465 The portion of the tool next to the fire expands more rapidly than the steel directly above it, and actually tears the colder metal apart.

466 (D) The fourth cause for cracks is too rapid heating in an intense fire. Even if properly turned over and over, the outside portions of a tool (particularly if it be of large body) are heated to a high forging heat before the center of the section has reached its proper temperature.

467 If hammered when in this condition, internal cracks in the tool are likely to be developed, because the center of the bar, instead of being malleable as the outside is, still remains comparatively cold and brittle, and the steel being unable to flow is torn apart, thus producing internal cracks. Internal cracks are also caused in some cases by hammering the outside of the bar with too light taps of the hammer. The force of the hammer blow should be powerful enough to penetrate to the center of the bar and should, therefore, increase with the size of the steel.

468 It is from the third and fourth causes (C and D) that cracks are most frequently developed and, therefore, slow heating and frequent turning of the bar in the fire are to be recommended, particularly during the early stages of heating. If the heat must be hurried, let it be during the final rise in temperature from the cherry red, say, up to the proper forging heat.

469 The above remarks refer of course to high speed tools, not to either tempered tools or the old self-hardening tools which should not be heated beyond a light cherry red in forging.

RELATIVE WORK TO BE DONE IN THE SMITH SHOP AND ON THE GRINDING MACHINE FOR MAXIMUM ECONOMY IN MAKING TOOLS

470 It requires much and careful observation, made not in a desultory manner but with a stop-watch, to determine the exact degree of accuracy with which the shape of the nose of the tool should be forged; in other words, to determine how much of the work of shaping the nose of the tool should be done by the smith and how much should be left for the grinder. It is evident that this will depend upon the method and the facilities in the machine shop for rapid and accurate grinding. If the grinding is done by hand, and on a grindstone or on a fine emery wheel, it will take a far longer time and be much more expensive than if done on an automatic grinding machine which is supplied with a corundum wheel, the size of the grit of which is carefully selected, so as to grind with the greatest rapidity while at the same time leaving a sufficiently smooth finish. The better and more rapid the grinding facilities then, the smaller should be the percentage of work done in shaping the tool in the smith shop and the larger the percentage done by the grinder, and vice versa.

LIMIT GAGE FOR DRESSING TOOLS

471 On Folder 6, Fig. 29, is shown a gage giving the forging limits which have been demonstrated to be most economical in forging a tool of the size shown on Folder 6, Fig. 28, in shops in which first-class automatic tool grinders are used. In shops in which tools are ground by hand on an emery wheel or grindstone, it will be found economical for the smith to shape the curve of the cutting edge of the tool within much closer limits than those given in this gage.

472 This limit gage is placed with its parallel shank on top of the body of the tool, while the curved slot is directly over the curved nose of the cutting edge, hence in dressing the tool, and in approximating the curve of the cutting edge, all that is required of the smith is that every portion of the outline of the cutting edge of the tool shall come within the limits of the curved slot. On looking down through the slot in the gage, the smith should see the whole outline of the cutting edge of the tool, and provided the whole line of the cutting edge as left by the smith is in sight through this slot, it is of no consequence whether the curve is irregular and jagged in shape or whether it is

left smooth. It will be cheaper for the grinder to grind off the irregularities in the curve than for the smith to take the extra time required for this purpose. Each type of tool used in the machine shop should be carefully studied in this way so as to establish the most economical limits within which the smith is to do his work, and limit gages similar to the one illustrated on Folder 6, Fig. 29, should in all cases be carefully made. The writer wishes to emphasize again the desirability of so designing tools and, particularly, of so adjusting the relative amount of work to be done by the grinder and the smith, that all sizes up to 1 x 1½ inch may be dressed in two heats, and still leave as little work as practicable for the grinder.

IMPORTANCE OF USING A HEAVY STREAM OF WATER DIRECTLY ON NOSE OF TOOL IN GRINDING TOOLS

473 In Par. 247 and 1016 attention is called to the great injury which is constantly being done to the modern high speed tools by heating the cutting edge too hot on the grindstone. It becomes of the first importance in grinding, whether an automatic tool grinder is used or whether tools are ground by hand, always to throw a heavy stream of water upon the nose directly at the spot where the emery wheel or grindstone is doing its work. The practice of pouring water upon the emery wheel above the tool and allowing the stone to carry the water along with it is to be avoided, as this method provides entirely too small an amount of water to properly cool the tool. We have found by experiment that it requires a stream of water of not less than five gallons per minute, thrown directly upon the cutting edge of the tool, to prevent its being overheated on the grindstone. Even then the man running the grinder should be under frequent supervision or the temptation to force the grinding, to hurry his work and thus to overheat the tool, may prove too great. The water should be thrown in a large stream with slow velocity to avoid splashing.

474 The necessity for not overheating the tool in grinding also modifies the shape for forging our standard tool. It will be noted that the noses of our standard tools as they come from the smith shop, shown Folder 2, Fig. 11 and 12, have clearance angles of 20 degrees, whereas a clearance angle of 6 degrees is ample for shop use. In other words, the noses of our standard tools lean far forward out of the perpendicular. The object of this is to make the distance beneath the cutting edge, which must be ground off of the flank each time the tool is sharpened as short as possible. In this way a smaller pressure between the tool and the grindstone is called for, the tool is ground

in a much shorter time, less heat is generated by the grindstone, and there is less danger of injuring the tool from overheating.

475 By noting also tool shown on Folder 2, Figs. 10 and 11, it will be seen that the nose when cut off by the blacksmith has a much more acute lip angle than is actually needed in the machine shop for cutting. This acute angle is given the tool for the same reason as was the extra clearance angle, namely, to diminish the extent of the surface which must be ground from the lip surface of the tool. The diminution in the grinding which results from leaning the nose of the tool forward and cutting a much steeper side slope in the smith shop becomes apparent from a comparison of Folder 2, Fig. 11, with the view of a tool dressed and ground in the ordinary way, as shown on Folder 7, Figs. 36, 37 and 38.

476 In drawings shown Folder 5, Figs. 25a to 25e, it will be noted in each case that broken lines above and beyond the upper part of the nose of the tool indicate the shape to which the tool is forged, while the solid, heavy lines indicate the shape to which the tool is ground at its first grinding.

477 Our reason for leaving so much metal in the forged tool to be ground off is that sometimes in giving the tool the high heat, owing to too slow a fire being used, the metal close to the surface of the nose of the tool is somewhat injured, and by grinding off this exposed point of the tool at its first grinding, a tool which runs at once at its highest cutting speed can be obtained.

TOOLS WITH KEEN LIP ANGLES (I. E., STEEP SIDE SLOPE) MUCH MORE EXPENSIVE TO GRIND THAN THOSE WITH BLUNT LIP ANGLES

478 While on the subject of grinding, it should be pointed out that the steeper the side slope of the lip surface, the larger becomes the area of the surface which must be ground and the smaller the number of times a tool of a given height can be ground before redressing. This will be clearly seen by inspecting Folder 5, Figs. 23, 20a and 20b; in one of which successive layers of $\frac{1}{32}$ of an inch of metal are to be ground off with a side slope of 14 degrees or at right angles to the vertical line, while in the other a side slope of 22 degrees is used in grinding.

479 A steep side slope also renders the cutting edge more likely to be overheated in grinding as it leaves a smaller cross-section of metal in the wedge-shaped section close to the cutting edge for carrying away the heat, as pointed out in paragraph 516.

480 If economy of grinding alone then were to be considered, a steep side slope in the tool would be avoided for every reason. A

consideration of the above facts will also make it more clear why all machinists who grind their own tools incline toward too little rather than too much side slope.

FLAT SURFACES TEND TO HEAT THE TOOLS IN GRINDING

481 Flat surfaces coming into contact with the emery wheel also tend very greatly to heat the tool, chiefly because the surface which is being worked upon is soon ground so as to fit so exactly and closely against the outside surface of the grindstone that no water can find its way between the stone and the tool and thus cool the latter. It is for the purpose of giving the water free access to the face of the tool being ground that in grinding tools by hand the best grinders invariably keep the tool more or less wobbling about upon the face of the grindstone while the greater part of the metal is being roughed off. For the same reason they hold the tool stationary against the stone only during the last stage of the grinding when finishing the lip surface to the exact angle required. In selecting an automatic grinder, no machine should be purchased which does not permit free access of the water to the flat surface of the tool during the operation of grinding.

482 It is for a similar reason also that tools with a curved cutting edge are to be preferred from the standpoint of grinding to those with a straight line on the cutting edge. The straight line always implies a flat clearance surface beneath the cutting edge for grinding, and a flat surface is far more difficult to grind without heating than a curved surface.

THE SELECTION OF THE EMERY WHEEL

483 The selection of the proper emery wheel for tool grinding is also a matter of great importance. The hardest grit obtainable should be used, and for grinding ordinary shop tools, so far as we know, corundum is the best. Rapid grinding is promoted by the use of a coarse grit in the wheel. On the other hand, too coarse grit leaves an irregular outline at the cutting edge of the tool. After experimenting with emery wheels varying greatly in their coarseness, we have adopted as our standard an emery wheel having a mixture of grits known as size No. 24 and size No. 30. A corundum wheel made of these two sizes of grit grinds fast and leaves a sufficiently smooth finish on the tool.

DESIRABLE FEATURES IN AN AUTOMATIC TOOL GRINDING MACHINE

484 Tools should never be ground by fastening them solidly in a slide or tool rest which is fed directly against the emery wheel with a screw; since soon after the grinding starts, the surface of the tool is made to fit exactly against the surface of the stone, after which grinding is exceedingly slow and the tool is rapidly overheated. It may almost be said that the moment a tool becomes a close fit against the side of the grindstone, grinding ceases and heating begins.

485 Much more rapid grinding can be done upon a grinding machine in which there is provided a means for automatically adjusting the pressure of the tool against the emery wheel. Each sized tool should have adapted to it a pressure which is automatic and which is just sufficient to grind rapidly without danger of overheating. An automatic machine of this type will do about twice the work of a machine in which the pressure between the tool and the emery wheel is regulated according to the judgment of the grinder.

DESIRABILITY OF A LARGE SUPPLY OF TOOLS, A COMPLETE TOOL ROOM, AND AN AUTOMATIC GRINDING MACHINE EVEN IN A SMALL SHOP

486 In Par. 115 etc. we have pointed out that the greatest gain from a study of the art of cutting metals can be attained only through reorganizing the system of management of the shop in such a way that it is possible to assign daily tasks to the workmen, and that in preparing for this a thorough system must be established for delivering to each workman an ample supply of tools ground to standard shapes ready for use. This involves a tool room with ample storage space for a large number of extra tools. For economy, even in a small shop, the tools should be ground in lots or batches; *i. e.*, there should be such an ample supply of tools in the shop that dull tools of a given size and shape can be allowed to accumulate until a lot, say, ten to twenty or more, is ready for the grinder. With this system it is economical for the small shop as well as the large one to use an automatic tool grinder.

487 In our experience in reorganizing the management of machine shops we almost invariably have difficulty in persuading the owners to maintain the large supply of tools which is needed to get the full benefit from the task system. It seems desirable, therefore, to lay particular stress upon all of the elements connected with the tool supply—of which accurate and rapid grinding without injuring the tool is the most important.

488 We would call attention to the fact that there is little if any economy in the use of an automatic tool grinding machine unless

standard shapes for all tools have been adopted, and unless a large supply of tools is kept in a well-equipped tool room, from which they are issued to the men, no workman being allowed to grind his own tools.

PRESSURE OF THE CHIP ON THE TOOL

489 In the following paragraphs 490 to 585 the subject of the pressure of the chip upon the tool will be dealt with at length, even although in most of its aspects an investigation leads to negative or more or less contradictory results. Indeed, our principal object in writing at such length upon this subject has been to endeavor to make it clear that, on the whole, a study of this element in the art of cutting metals is comparatively barren of practical results. It is our hope, therefore, that we may convince our readers that a study of the pressure of the chip on the tool leads to few useful conclusions so far as the vital question of cutting speeds is concerned.

490 As indicated in paragraphs 73, 75 and 92, this element has been the subject throughout the world of perhaps four-fifths of all the experiments connected with the art. And yet we believe that our contention that greater progress would have been made if no experiments whatever had been undertaken in this particular field is thoroughly borne out. The chaotic results obtained through these pressure experiments have unquestionably held back further scientific research in the whole art, and led experimenters to the conclusion that after all this subject belongs to the domain of "rule of thumb" rather than to that of exact science. If, therefore, the writing of this paper shall result in diverting the attention of future experimenters from this field to the many more useful lines of investigation, we feel that one of our chief aims will have been realized.

SUMMARY OF CONCLUSIONS OF ENGLISH, GERMAN AND AMERICAN EXPERIMENTERS

491 On Folder 12, Table 83, are given the broad conclusions arrived at by experimenters in Germany, England, and this country, respectively, as to the pressure of the chip upon the tool in cutting steel and cast iron. The figures from the German experiments are taken from an article by Herman Fischer (published in "Zeitschrift des Vereines Deutscher Ingenieure" of May 1, 1897), who, after reviewing various German experiments made from time to time and considering their reliability, states that, according to the hardness of the material, the

shape of the cutting edge of the tool, including the clearance and lip angles and its dullness within permissible limits, and the relation between the length and thickness of the chip which is being cut, the pressure per square inch of section of the chip varies between the limits given in the table. He also recommends that in designing machine tools, the higher figures for the cutting pressures be counted upon.

492 Dr. Nicolson in summarizing the Manchester experiments and his own experiments made later with his highly perfected apparatus, has concluded that the pressure on the tool is directly proportional to the sectional area of the cut, that is, of the layer of metal being removed by the tool. He concludes that the pressure for the same total area is the same whether the thickness of the chip be fine or coarse. This is not in agreement either with the German experiments or our own, as the latter show increasing pressures as the thickness of the chip diminishes, particularly in the case of cutting cast iron. (See paragraphs 546 to 558)

493 It must be noted, however, that in the Manchester experiments $\frac{1}{16}$ of an inch was the finest feed taken whereas our experiments indicate a greater proportional increase in pressure as the feeds become finer than $\frac{1}{16}$ of an inch. Our experiments indicate that the pressures vary between the limits given on Folder 12, Table 83. In the case of steel they slightly increase as the thickness of the shaving diminishes; and in the case of cast iron very materially increase as the thickness of the shaving diminishes.

494 As to the effect of cutting speed upon the pressure of the chip, the conclusions from the Manchester experiments and from our own are that there is but slight difference in pressure between fast and slow cutting speeds, but that the total power required to remove a given amount of metal is less at fast than at slow cutting speeds, owing chiefly to the diminution in the frictional resistance of the machine tool and its drive at higher speeds.

495 Dr. Nicolson's experiments indicate that the outward or "surfacing" pressure upon tools or the pressure tending to push the tool away at right angles to the axis of the work varies according to the contour of the cutting edge and the lip and clearance angles of such tools as are in common use between the limits of 18 per cent and 90 per cent of the vertical pressure upon the tool, while the feed or "traversing" pressure upon similar tools vary between zero and 20 per cent of the vertical pressure.

496 In measuring the outward and feeding pressures Dr. Nicolson has designed much the most scientific apparatus which has yet

been made. Nevertheless, engineers must be warned not to use the feeding pressure obtained by him in designing machine tools, as both the German and our own experiments indicate that at times the feeding pressure is equal to the entire downward pressure on the tool. Doubtless Dr. Nicolson would have arrived at the same conclusion had he made more experiments, and particularly with tools which are too dull for proper shop use. This degree of dullness, however, will occur on every machine tool sooner or later, and the pressure corresponding to it must, therefore, be the limiting figure used in designing feed gearing, as otherwise the feed gears will be broken.

497 In paragraph 97, (Part 1) of this paper, the writer has made the assertion that it is his opinion that if no experiments whatever had been made upon the pressure required to remove the chip, the knowledge of the art of cutting metals would on the whole be in a more advanced state than it is now, since experimenters in all countries in this field, instead of almost wholly wasting their time in pressure determinations would have given their attention to some one of the other lines of investigation which bear directly and yield valuable information upon the one most important subject of cutting speed.

498 Before entering upon the details of our experiments upon the cutting pressure, it seems desirable to explain briefly, first, the facts upon which the above assertion rests, and, second, if possible to give an adequate explanation for these facts.

499 In 1883 in the works of Wm. Sellers & Co., of Philadelphia, a series of experiments was made by Messrs. Wilfred Lewis and John Bancroft with a dynamometer, in which the pressure of the chip upon the lip surface of the tool was measured. These experiments showed that for steels varying greatly in hardness and consequently in their cutting speeds, the variation in the pressure of the chip upon the tool in no way corresponded either to the hardness of the steel or to the speed at which it could be cut. A further study of the results of these experiments indicated also that there was no clearly defined and traceable relation between the tensile strength or the crushing strength of steel and the cutting speed. These results agreed accurately with the observations, which we had made in our many experiments on cutting speeds. Namely, that lathes, boring mills, etc., are able to pull about as heavy cuts with hard as with the soft steels, although there is a very great difference between the cutting speeds of hard and soft steels. Having established this important fact to our satisfaction and having through these experiments obtained sufficient data for properly designing machine tools as to the power required to cut metals, no fur-

ther experiments were made by us in this line until the year 1902, when the subject was again more carefully investigated through dynamometer experiments in the shop of Wm. Sellers & Co. These experiments will be described later in this paper.

500 In the Manchester experiments (described in paragraphs 77 to 92) the pressures of the chip upon the tool were carefully recorded and averaged, and the metals experimented upon were chemically analyzed and test bars broken to determine their physical properties. A summary of these experiments in cutting steel forgings, as they bear upon the relation of cutting speed to pressure on the tool and to the tensile and crushing strength of the metals being cut, has been tabulated on Folder 12, Fig. 81, together with our own experiments on the same subject, and on Folder 12, Fig. 80, are tabulated corresponding experiments made in cutting cast iron bars of varying hardness.

501 In the five columns, side by side, will be noted in heavy-faced type the more important elements which should be studied in their relations one to another, namely:

a The cutting speed in feet per minute;
b pressure of chip on the tool in tons (2000 lbs.) per square inch of sectional area of the shaving;
c tensile strength in tons (2000 lbs.) per square inch;
d percentage of stretch in test bars;
e crushing strength in tons (2000 lbs.) per square inch.

CUTTING SPEED AND PRESSURES OF CHIP ON THE TOOL COMPARED FOR STEEL

502 Referring to Folder 12, Table 81, on "Pressure on Tool in Cutting Steel Forgings and Castings," it is a matter of common knowledge that as the percentages of carbon and manganese increase in steel, the metal grows harder, and that corresponding to this increase of hardness, the cutting speed grows slower and slower. By looking in the carbon column and then in the cutting speed column of the table, the slowing down in the cutting speed corresponding in a general way to the increase in carbon will be apparent. On the other hand, when we compare the tensile strength in tons (2000 lbs.) with the cutting speed, we should expect here also to find that as the tensile strength of the steel increases, the cutting speed diminishes. This is, however, not the case, and a very marked and at first unaccountable irregularity exist between the tensile strength and the cutting speed. Although it may be said that in a very general way steels having higher tensile strength tend toward lower cutting speeds.

503 When we examine, however, the more important sub ect of the relation of the pressure on the tool to the cutting speed, it is astonishing to note that there is no traceable relation whatever between the two. For example, referring to line 1 of the table a pressure of 128 tons upon the tool is accompanied by a cutting speed of 111 feet per minute, while on line 5 a pressure of 128 tons has a cutting speed of only 35 feet per minute, while again on line 2, 121 tons pressure on the tool has only 80 feet cutting speed. To a considerable extent also, there is the same lack of agreement between the tensile strength of the steel and the pressure of the chip on the tool. For example, on line 3 a tensile strength of 52 tons is accompanied by a pressure on the tool of 168 tons while on line 7 a tensile strength of 48 tons has a pressure of only 92 tons.

504 These statistics leave the student of this subject in a most chaotic state of mind, and of the many anomalies and surprises met with by experimenters in the art of cutting metals, the most baffling and apparently unaccountable are the following facts:

505 No law can be established or formulated for cutting steel which expresses either

a the relation between cutting speed and the pressure on the tool; or

b the relation between cutting speed and the tensile and crushing strength of the metal to be cut.

THEORY AS TO WHY NO ACCURATE RELATIONS EXIST BETWEEN PRESSURE ON TOOL AND CUTTING SPEED, TENSILE STRENGTH, ETC.

506 Generally speaking, theories must be accepted with less confidence than facts. The writer, however, ventures to offer the following theory in explanation of the above phenomena as at least corresponding closely to the facts.

507 It will be recalled that although the tensile strength of soft steels is much lower than that of hard steels, yet in many cases it requires more foot pounds of energy to break by pulling apart in a testing machine a test bar of low tensile strength than one of high tensile strength. The reason for this is that the percentage of stretch or extension in the soft steel bar is in most cases much greater than that in the hard steel. (See tensile strength, stretch, and carbon columns of Folder 12, Table 81) When we consider the fact that throughout the time that a test bar is stretching, all of the grains inside of the bar are continually flowing, moving or sliding past one another under what may be called very heavy internal friction, it becomes clear that

in spite of the fact that the pull or power required to cause flow in the grains or crystals of the soft steel is less than the pull required to move the grains of a hard steel bar, yet the greater distance through which the grains of the soft steel continue to flow more than makes up for the difference of tensile strength in the final sum total of energy expended.

508 In paragraphs 155 to 169 the writer has indicated the fact that in tearing a chip from a bar of steel, the grains or molecules of the metal of the chip are caused to flow past one another under very severe compression for a considerable distance, so that the thickness of the layer of metal being removed is double in the chip what it was originally on the forging. In the case of a chip torn from soft metal, the movement or flow of the grains of the chip past one another is much greater than in the case of a hard chip. In other words, a soft steel chip is thickened up in cutting much more than a hard steel chip.

509 Thus it becomes clear why in cutting a chip the total energy expended and the pressure of the chip on the tool are in many cases greater with a soft steel than with a hard steel.

510 Attention is called to the fact that in cutting soft steel, owing to the fact that it thickens more than the hard steel, the chip bears upon the lip surface of the tool over a much larger area than in cutting hard steel, see Folder 8, Fig. 43 and 44, and although undoubtedly the intensity of the pressure on any one small spot on the lip surface of the tool is greater in cutting hard steel than in cutting soft steel, yet the larger area which is under pressure with the soft steel chip more than makes up in many cases for the difference in the intensity. Therefore, frequently a heavier total pressure is produced with the soft steel than with the hard. It should be noted, however, that in breaking a tensile test bar, the molecules or grains of metal in most cases continue to flow or move past one another until the entire metal of the bar has reached close to its maximum possibility of flow, and until it is at all points ready for rupture, almost all of its potential flowing energy having been exhausted. But in the case of the pressure of the tool upon the chip, the conditions are evidently such that the tool cannot completely use up all of the potential energy in the metal which is being cut, so that doubtless each of the small elements into which the chip breaks up could be crushed and the grains caused to flow past one another still further before entirely reaching the collapsing point. In other words, breaking a tensile test bar is a more efficient means of using up the potential flowing energy of steel than is the crushing action of the tool in removing the chip. If the two methods were equal in using up flowing energy, then we should expect to find the pressure on the tool directly propor-

tional to the tensile or crushing strength of the steel multiplied by its percentage of stretch. This is not, however, accurately the case, and, generally speaking, the harder the steel being cut, the larger the proportion of potential flowing energy that will be used up by the tool in cutting the chip, so that of the two elements or properties of steel which tend to increase the pressure of the chip on the tool—*i. e.*, the tensile strength of the metal and its percentage of stretch—the tensile strength counts for most in producing pressure on the chip. (See paragraphs 572 to 575)

511 The pressure of the chip on the tool is doubtless greater, the finer the quality of the metal which is being cut, *i. e.*, in metals which combine both a high tensile strength and a comparatively large percentage of stretch; such, for instance, as the fine qualities of low phosphorous steels which have been most carefully worked in forging, or the thoroughly oil tempered and annealed gun forgings, or high grades of tool steel, in all of which exceedingly high combinations of tensile strength and stretch are attained. And again it should be noted that although the pressures on the tool are high in these fine qualities of steel, yet the cutting speeds are by no means proportionally slow. The slowest speeds are to be found in cutting chilled iron or more or less hardened steels, which generally have an exceedingly low percentage of stretch and also comparatively low pressures on the tool.

512 An illustration of this will be seen by referring to Folder 12, Table 81, which furnishes the comparison given below of three pieces of me al. In the first line will be found a forging consisting of a good quality of hard steel experimented upon in the Manchester experiments, and in the second and third lines a steel roll and a car wheel casting necessarily inferior in quality to a forging experimented upon by Wm. Sellers & Co., of Philadelphia. Both of the steels tested by Sellers are evidently inferior to the Manchester steel.

The details of these three experiments are as follows:

KIND OF METAL	CARBON PER CENT	TENSILE STRENGTH IN TONS (2000 LBS.)	PERCENTAGE OF STRETCH	PRESSURE OF CHIP ON TOOL IN TONS (2000 LBS.)	CUTTING SPEED IN FEET PER MINUTE
Steel forging	0.50	52	14	168	41
Steel roll	0.55	51	8	128	35
Steel car wheel casting	0.82	48	3	92	22

513 It will be noted that the percentage of carbon of this forging and roll are about the same, and that the tensile strengths of all three are also about the same. On the other hand, the stretch of the roll is only a little more than one-half that of the forging, showing an inferior quality of metal. The casting has a still lower stretch and is of still lower quality, because it has not received work under the hammer. And this falling off in the quality of the metal indicated by low stretch is also accompanied by a falling off in the pressure of the chip upon the tool; the casting having only 92 tons, the roll having only 128 tons pressure, while the forging has 168 tons. Thus we see that an inferior quality of metal is accompanied by a lower pressure upon the tool. If the metal in the casting had been forged, its tensile strength would probably have not greatly increased, but it would without doubt have had a very materially higher percentage of stretch, and the pressure on the tool would have increased accordingly.

514 It will be noted that the car wheel casting, which gives a pressure on the tool of only 92 tons per square inch sectional area of the shaving, has a slower cutting speed than any of the other samples of steel which were cut, and yet it has the lowest total pressure on the tool of any steel. This is an excellent illustration of the fact that the hardness in steel which causes a low cutting speed is not accompanied by the highest pressures on the tool. On the other hand, this steel casting has only 3 per cent of stretch and it is undoubtedly this low percentage of stretch which accounts for the slow cutting speed. We shall attempt to fully explain this point later in the paper.

515 It is undoubtedly true that the heat[1] which is caused by the pressure of the chip upon the surface of the tool is, broadly speaking, directly proportional

a to the pressure of the chip upon the tool;

b to the cutting speed (*i. e.*, the velocity with which the chip slides across the lip surface);

c to the coefficient of friction between the chip and the tool, which is dependent upon the roughness of the lip surface and undoubtedly grows greater as the surface becomes softer.

516 On Folder 8, Figs. 43 and 44, on an enlarged scale are shown

[1]Dr. Nicolson, in his criticism of this paper, calls attention to the fact that more heat is generated in bending the chip or causing the molecules of the metal of the chip to flow past one another than through the friction of the chip on the tool.

the noses of two tools, one cutting a chip of hard steel and the other one of soft steel. The layer of metal being removed from the forging is in both cases of the same thickness. However, it will be noted that the soft steel chip where it presses upon the tool has become very much thicker than the hard steel chip, and also that it bears upon almost twice the area of the lip surface of the tool as does the hard chip. In each view the arrow indicates the center of pressure of the chip upon the lip surface of the tool; and it should be observed that the softer the steel, *i. e.*, the greater its per cent of stretch, the further is the center of pressure of the chip removed from the cutting edge. Now, as explained hereafter, the heat produced by the friction of the chip must be carried away principally down through the nose to the body of the tool. In each view the line $A-B$ represents the section of the tool opposite the center of pressure of the chip which is available for starting the heat on its way downward. It will be noted that the section $A-B$ in the case of the hard chip is much smaller than it is in the case of the soft chip, while at the same time it is much closer to the cutting edge of the tool. Thus, even assuming that the total heat produced by the soft steel chip is greater than that produced by the hard steel chip, nevertheless, on the one hand, there is much more metal available in the case of the soft steel chip for carrying the heat away; and on the other hand; the center of heat, $A-B$, is further away from the cutting edge, which is that portion of the tool which finally gives out. In addition to this, owing in the case of cutting the hard metal to the small bearing of the chip on the lip surface, the pressure is doubtless much more intense (*i. e.*, greater per square inch of the lip surface under pressure), and therefore in this case the lip surface of the tool must remain much harder in order to resist wear.

517 It will be observed then that all of these conditions combine to necessitate a slower cutting speed for hard metals than for soft, even if the total pressures of the chip on the tool were to be exactly the same for hard and soft metals. To summarize:

a In cutting hard metals the intensity of the pressure per square inch of the lip surface of the tool which comes in contact with the shaving is much greater than in cutting soft metals;

b the center of pressure is much closer to the cutting edge;

c the section of metal directly below the center of pressure is smaller for carrying the heat away.

518 All of these conditions which tend greatly toward lowering the cutting speed are brought about not so much through the greater

crushing strength of hard steels as through the smaller percentage of stretch in hard steels (*i. e.*, a smaller capacity for flow).

519 In paragraphs 1129 to 1165, relating to the classification of various metals according to their hardness, it will be pointed out that extending over quite a considerable range in hardness, a well defined law appears to exist, and a formula has been developed in which the cutting speed of steels is shown to bear a clearly defined relation to certain combinations of tensile strength and percentage of stretch.

CUTTING SPEED AND PRESSURE OF CHIP ON THE TOOL COMPARED FOR CAST IRON

520 Referring now to Folder 12, Table 80, on the "Pressure of the Chip on the Tool in Cutting Cast Iron," by examining the columns for cutting speed and the pressure of the chip in tons (2000 lbs.) it will be noted that there is also here no direct relation between the cutting speed and the pressure on the tool. For instance, a pressure of 94 tons per square inch of sectional area of the chip of medium cast iron is accompanied by a cutting speed of 49 feet per minute, while a pressure of only 92 tons is accompanied by a speed of 32 feet per minute; yet, as explained in pars. 93 and 503, one would naturally expect higher pressures on the tool to be accompanied by slower cutting speeds.

CUTTING SPEED AND CRUSHING STRENGTH COMPARED FOR CAST IRON

521 In comparing the crushing strength with the pressure on the tool, the two seem to be more nearly in inverse proportion one to the other in the case of cutting cast iron than in the case of cutting steel, and yet we have the two combinations of

a 49 tons crushing strength with 49 feet cutting speed; and

b 47 tons crushing strength with 32 feet cutting speed, showing that there is no constant relation between the two.

CAST IRON AND STEEL COMPARED IN THE RELATION OF CUTTING SPEED TO PRESSURE ON TOOL

522 In comparing cast iron and steel in the relation of pressure of the chip on the tool to the cutting speed, it is surprising to note that:

523 Generally speaking, the cutting speeds of cast iron are slower than the cutting speeds of steel, while at the same time the pressure of the chip on the tool in cast iron is much less than the pressure on the tool in cutting steel. The theory which we have advanced, however, in paragraphs 506 to 519, appears to account for this differ-

ence. It is well known that there is almost no stretch in breaking a cast iron test piece, nor does a compression bar yield to any great extent before the cast iron entirely crumbles. This lack of stretch, as explained, indicates the inability of the grains of cast iron to flow past one another under pressure; and since the metal has no ability to flow, the whole pressure of the chip is concentrated on the lip surface of the tool very close to the cutting edge, so that per unit of area of the lip surface in contact with the cast iron shaving the intensity of pressure is probably as great as in that of the steel chip. It is also probable that cast iron containing more carbon in t .e form of gritty graphite which is combined in a very hard state, is more abrasive in its action on the tool. All of these conditions tend toward rapid wear of the tool close to the cutting edge, and, therefore, also toward slow cutting speeds.

524 It is notable that the whole tool is heated to a much lower heat in cutting cast iron than in cutting steel, and yet the tools give out at slower cutting speeds.

APPARATUS USED AND METHOD OF MAKING EXPERIMENTS ON THE PRESSURE OF CHIP ON THE TOOL IN CUTTING CAST IRON AND STEEL

525 Two series of experiments for determining the pressure of the chip on the tool in cutting steel and cast iron have been made by us. One set made in 1884, in the Midvale Steel Works, Nicetown, Philadelphia, is of interest only in relation to the power required to feed the tool. The second set was made with greater care and with better appliances in 1902 in the shop of Wm. Sellers & Co., Philadelphia. The latter experiments only will be described in detail.

526 With the object of warning any future experimenters against the adoption of certain methods in this field, it seems desirable to briefly describe one method which after trial proved to be unreliable and was abandoned by us.

527 A lathe swinging 16-inch diameter over the shears and 13½ inch diameter over the saddle was driven by a 20 horse power motor using a current of 220 volts; with a belt running directly from the pulley on the motor to the cone pulleys on the lathe. These cone pulleys drove with the following gearing intervening between them and the face plate of the lathe. Pinion on sleeve of cone pulley: 15 teeth, 3 per inch, 5-inch pitch diameter, 4½ inch face. Wheel on spindle: 120 teeth, 3 per inch, 4-inch pitch diameter, 4-inch face.

528 Many trials were made to determine the pressure of the chip on the tool by first reading the ammeter while the motor was running

without the cut, and then noting the difference in its reading after the tool was cutting, and assuming that the difference in the power used in the two cases was equal to the work done by the tool.

529 This method proved unsatisfactory as the fluctuations of the needle of the ammeter were so great under light loads that it was found impracticable to judge with accuracy its average reading. Therefore, as an error in estimating the amperes of current not only directly affects the electrical power expended, but even still more affects the determination of the efficiency of the motor when running under light loads, this method was abandoned as unreliable.

530 An endeavor was then made to work the motor constantly under a heavier load by attaching an accumulator pump to it in addition to running the experimental lathe. This, however, also proved unsatisfactory, owing to fluctuation in the power of the pump.

APPARATUS USED IN EXPERIMENTS ON PRESSURE OF CHIP ON THE TOOL

531 The following simple device was then adopted, with which accurate results were obtained, and which were repeatedly re-duplicated, thus proving at least the uniformity of the whole method.

532 A rope brake was used on one of the steps of the cone pulley of the lathe. This brake, illustrated on Folder 9, Fig. 51, was at that time a somewhat recent improvement on a Prony brake, and consisted merely of a double rope slung around the pulley, having each of its ends attached to spring balances, one of which is stationary and the other of which is attached to the end of a draw screw, which is tightened or loosened by means of a hand wheel whose hub is used as a nut for the screw. The method of experimenting with this apparatus is as follows:

533 After the tool has been run for a sufficient length of time under cut to bring both the tool and the lathe to what may be called natural conditions as to wear, heat, friction, etc., the reading of the ammeter is noted as accurately as possible while the tool is under pressure. The tool is then removed and the brake is adjusted upon one of the steps of the cone pulley, and tightened until the ammeter reads the same as it did when the tool was under cut. At the same time the readings of the two spring balances are taken; and, since the difference in the readings of the two balances is the effective pull caused by the friction of the brake reduced to the central diameter of the brake rope, by multiplying this pull by the central diameter of the rope and by the ratio of reduction from the cone pulley to the lathe spindle, and then dividing this product by the mean diameter of the

forging upon which the cut was taken, the quotient obtained gives the pressure on the tool. In this way all of the power lost through friction throughout the entire apparatus is eliminated with the exception of the small difference in the frictional resistance of the bearings and gears which lie between the brake and the tool. It will be observed that the difference in the friction of these parts is small between the two cases when, on the one hand, the tool is cutting, and, on the other hand, the brake is tightened. This difference (unmeasured when the brake is on) must be proportional to the pressure on the tool and, therefore, will in no way affect the relative pressures of the different cuts.

534 It should be noted that it is necessary to take the reading of the ammeter and the two spring balances as soon as practicable after the brake is applied, and before the cone pulleys and ropes become so heated as to cause variation in the frictional resistance of the brake. When this is done, the method is both delicate and accurate.

DETAILS OF EXPERIMENTS UPON THE PRESSURE OF THE CHIP ON THE TOOL IN CUTTING CAST IRON WITH OUR STANDARD TOOLS WITH VARIOUS FEEDS AND DEPTHS OF CUT

535 The following are the general conclusions arrived at on this subject:

536 (A) Total pressure of chip on tool in cutting cast iron of the different qualities experimented upon by us varies between the low limit of 35 tons (2000 lbs.) per square inch sectional area of chip for soft cast iron, when a coarse feed is used, see Folder 12, Table 83, and Folder 13, Table 92, and 99 tons (2000 lbs.) per square inch sectional area of chip for hard cast iron, when a fine feed is used. (See Folder 13, Table 92; also paragraphs 544, etc., and 491)

537 (B) In cutting the same piece of cast iron, the pressure of chip on the tool per square inch sectional area of chip grows considerably greater as the chip becomes thinner, and slightly greater as the cut becomes more shallow in depth. The following are the high and low limits of pressure per square inch of sectional area of the chip when light and heavy cuts are taken on the same piece of cast iron. (See Folder 13, Table 92, column for 1¼ inch tool)

Depth of cut ¼ inch × feed 0.0328 inch : Total pressure per sq. in. sectional area of chip, 128,000 lbs.;

Depth of cut ¼ inch × feed 0.1292 inch : Total pressure per sq. in. sectional area of chip, 75,000 lbs.

538 (C) The same fact mathematically expressed is that in cutting

the same piece of cast iron, the pressure of chip on the tool per square inch sectional area of chip grows greater as the thickness of the chip grows less in proportion to (thickness of the feed)$^{\frac{1}{4}}$ or $F^{\frac{1}{4}}$. (See paragraph 546)

539 The pressure of chip per square inch of section also grows greater as the depth of the cut grows less in proportion to (depth cut)$^{\frac{1}{8}}$ or $D^{\frac{1}{8}}$. (See paragraph 546)

540 (D) The effect upon the pressure of the chip on the tool of a change in the thickness of the feed and the depth of the cut is the same for hard and soft cast iron, and is represented by the same general formula, with a change merely of the constant. (For formula, see paragraph 546, and for description of experiment on which this fact is based, see paragraph 562)

541 (E) In taking cuts having the same depth and the same feed, the pressure of the chip on the tool becomes slightly greater the larger the cutting tool used. This increase in the pressure follows from the fact that the larger the curve of the cutting edge of the tool the thinner the shaving becomes. (See paragraphs 307 and 559)

OBJECTS OF EXPERIMENTS ON PRESSURE

542 The principal object in making the experiments described in detail below was to determine, broadly speaking, the maximum pressures upon the tool per square inch of sectional area of the chip, both in cutting soft and hard cast iron, when our standard shop tools of different sizes were used; this information being needed in designing machine tools, for this purpose the highest pressure of 99 tons (2000 lbs.) as indicated on Folder 13, Table 92, should be sufficient.

543 Our secondary object, and one of almost equal importance, was that of obtaining the pressure on the tool per square inch of sectional area of the chip being cut, corresponding to various changes in the depth of cut and in the thickness of the feed. This information is needed in determining by means of our slide rules, described in paragraph 1188 the exact sized cut which each machine tool is capable of taking under its possible combinations of pulling power, speed and changes in the thickness of feed.

544 On Folder 13, Table 92, will be seen a summary of the actual pressures obtained under various conditions in these experiments, and in adjoining columns the pressures are reduced to pounds per square inch of sectional area of chip. The same data are recorded in the diagrams, Folder 13, Figs. 87 to 91, by means of round spots which

are connected in series one with another by faint lines, so that all of the experiments made with the same depth of cut can be readily compared.

545 On the left-hand side of each of these diagrams are recorded the regularly increasing pressures of the chip upon the tool; while on the bottom line are recorded the regular increases in the thickness of the feed.

546 In a series of heavy lines on each diagram are drawn curves corresponding to the following formula, which expresses the general relation existing between the depth of cut and the feed, and the pressure on the tool for all of the grades of cast iron experimented upon:

$$P = C\, D^{\frac{1}{2}}\, F^{\frac{1}{2}}$$

in which

P = The pressure on the tool;
D = Depth of cut in inches;
F = Feed in inches;
C = A constant depending upon the softness or hardness of the cast iron, and which varies between the limits of 45,000 for soft and 69,000 for hard cast iron, as experimented on by us.

547 On Folder 13, Fig. 87, are combined all of the various experiments given in detail in the other diagrams. In these diagrams the heavy lines represent the same formula above referred to, while the round spots which are grouped together in series indicate all of the pressures obtained with the various sized tools used and with the different feeds and depths of cut taken in the several sets of experiments.

548 It will be noted that, on the whole, the law expressed by this formula corresponds very closely to each of the several series of experiments. These experiments were made on different dates, and the pressures were accurately recorded without reference in any case to the data obtained in former experiments. And the fact that they all, on the whole, so closely conform to the same general law, tends greatly toward confirming both the value of the apparatus and of the method employed, and also the accuracy and care of the experimenters.

549 It will be remembered, as stated above, that the conclusion drawn from the Manchester experiments was that the pressure of the chip upon the tool per square inch of sectional area of chip was directly proportional to the area of the chip and was the same whether light or heavy cuts were taken, and that it did not depend upon either the thickness of the feed or the depth of the cut. This conclusion is at

variance with our experiments and with the formula in paragraph 546, which mathematically expresses our results. It may be claimed that the slight difference in the friction of the machine, as referred to in paragraph 533, caused our records to indicate slightly heavier pressures than those actually received by the tool, and that the difference between the results of our experiments and the Manchester experiments can be explained in this way. Unquestionably this slight error in the frictional resistance tends towards recording pressures somewhat higher than the actual pressures; but since, as indicated in paragraph 533, the errors are proportional to the pressures, it is evident that it in no way accounts for the relative difference between thick and thin shavings in results obtained by the two sets of experiments. The following data further confirm this reasoning, and also the correctness of our conclusion that the pressure per square inch of sectional area of chip increases as the chip grows thinner.

550 In the comparison given below we have taken the data from two experiments made with the same tool upon the same piece of cast iron. (See Folder 13, Table 92)

DEPTH OF CUT	THICKNESS OF FEED	TOTAL SECTION OF CHIP	PRESSURE IN LB. ON TOOL PER SQUARE INCH OF SECTIONAL AREA OF CHIP
$\frac{1}{8}''$	0.0916	0.01145	102000
$\frac{27}{64}''$	0.0220	0.00928	117000

551 It will be noted that in both of these experiments chips having approximately the same sectional area were cut, but in one case a thin feed and a deep cut were used; while in the other case a thick feed and a shallow cut were used; and that in spite of the total areas being approximately the same, the thin feed was accompanied by a materially higher pressure per square inch than the thick feed.

552 In all such instances, it is clear that the frictional error, if any, caused by our apparatus is entirely eliminated as far as it affects thin or thick chips. Many more similar illustrations of this fact can be taken from the data recorded in the tables.

553 Further evidence confirming the fact that the pressure varies

with the thickness of the shaving will be seen by referring to paragraph 559, and it should be noted also that in this matter the German experiments are in agreement with ours.

554 As stated above in paragraph 549, the Manchester experiments do not extend to feeds as fine as those taken in ours, and for this reason it is possible that the results obtained by them were in this particular misleading.

555 This paper is of necessity so voluminous that the subject of drilling metals will not be dealt with. But as confirming the conclusion drawn from our pressure experiment, that the pressure per square inch increases as the chip becomes thinner, we reproduce on Folder 12, Fig. 85, a diagram showing the results obtained by Professors Bird and Fairfield, of the Worcester Polytechnic Institute of Massachusetts, in their experiments on the power and pressure required in drilling cast iron, as published in the Transactions, Vol. 26, p. 362.

556 The diagram gives the twisting moments recorded in drilling a ¾-inch hole with feeds varying from 0.004 inch to 0.02 inch, and the curve shown represents the formula (developed by Mr. Barth),

$$M = 1470\ F^{\frac{3}{5}}$$

in which M = the twisting moment in inch-pounds; and
F = the feed in inches per revolution.

557 It is evident that this twisting moment is directly proportional to the pressure of the chip against the lips of the drill; and hence this resistance is also proportional to $F^{\frac{3}{5}}$. But this exponent $\frac{3}{5}$ is even smaller than the exponent $\frac{3}{4}$ for F in the formula developed by Mr. Barth to cover the results of our experiments on cutting pressures on cast iron (see paragraph 546), and thus indicates a proportionally still greater increase of the pressure with a decrease in thickness of the chip; or, what is the same thing, a proportionally still greater decrease in the pressure with an increase in the thickness of the chip.

558 This experiment confirms the results obtained by us that the pressure increases as the chip becomes thinner, as against the conclusions arrived at in the Manchester experiments.

THE EFFECT OF THE SIZE OF THE STANDARD TOOL UPON THE PRESSURE OF THE CHIP ON THE TOOL

559 On Folder 13, Fig. 90, are plotted the pressures obtained in cutting a piece of soft cast iron while using one of our standard 1¼-inch tools. On Folder 13, Fig. 89, are plotted a corresponding series of pressure determinations made upon the same piece of cast iron and using a ½-inch tool. These two sets of experiments were purposely made upon

exactly the same piece of cast iron to determine the effect of the size of the nose of the tool upon the pressure. The results very clearly confirm the conclusion given above, namely, that the pressure increases as the thickness of the chip diminishes.

560 Earlier in the paper we have indicated that in using a large sized tool with a given depth of cut and feed, the chip is thinner than in using a small tool, and that as the depth of cut increases, the difference in the thickness of the chip becomes more marked when taken by a large tool than by a small tool. Now, by referring to Folder 13, Fig. 90, with depth of cut of $\frac{7}{64}$ inch, in which a large tool was used, it will be noted that all of the spots lie almost directly upon the line of the curve, whereas by referring to the corresponding diagram, Folder 13, Fig. 89, for the small tool, it will be seen that these spots lie considerably below the line, thus showing lower pressures corresponding to a greater thickness of chip.

561 When shallow depths of cut are taken, there is comparatively little difference between the thickness of the chip as taken by the small tool and the large tool, and here it is obvious also that the pressures obtained with the two tools more nearly correspond.

THE EFFECT OF A THIN CHIP AND SHALLOW DEPTH OF CUT IN INCREASING THE PRESSURE ON THE TOOL IS THE SAME FOR HARD AS FOR SOFT CAST IRON

562 On Folder 13, Table 92, and Folder 13, Table 90, will be noted the actual pressures obtained in experiments, on the one hand, on soft cast iron, and on the other hand, on hard cast iron; and on Folder 13, Fig. 90, and Folder 13, Fig. 91, are recorded graphically the same data. These diagrams together with the formula beneath them, which represents the two sets of experiments, indicate that generally speaking the effect upon the pressure of chip on the tool of thinning the shaving and of making the depth of cut shallow is the same for hard as for soft cast iron. The only difference between the two is that the pressures are uniformly higher in cutting hard than in cutting soft cast iron. This fact will be seen in detail by a comparison of the following figures.

563 If we select from the table of pressures on the soft cast iron a light and heavy cut, and a similar light and heavy cut from the table for hard cast iron, as follows:

	DEPTH OF CUT IN INCHES	THICKNESS OF FEED IN INCHES	TOTAL SECTION OF CHIP IN SQUARE INCHES	PRESSURE IN LBS. ON TOOL PER SQUARE INCH OF SECTIONAL AREA OF CHIP
Soft Cast Iron	$\frac{1}{4}$	0.0635	0.00785	114000
	$\frac{1}{11}$	0.0909	0.05695	78000
Hard Cast Iron	$\frac{1}{4}$	0.064	0.008	178000
	$\frac{1}{11}$	0.09	0.05695	122000

564 It will be noted that the relative pressures on the chip in the two cases are approximately the same. This is indicated by the following proportion, the figures of which are taken from our tables:

Pressure per sq. in. soft cast iron thin chip (114-000) : Pressure per sq. in. soft cast iron thick chip (7800) = Pressure per sq. in. hard cast iron thin chip (178-000) : Pressure per sq. in. hard cast iron thick chip (122-000)

565 A comparison of the two formulæ given below for soft cast iron and hard cast iron show clearly that the ratio is the same between the two for the different hardnesses of iron.

For soft cast iron $P = 45000\ D^{\frac{11}{4}}\ F^{\frac{1}{2}}$

For hard cast iron $P = 69000\ D^{\frac{11}{4}}\ F^{\frac{1}{2}}$

or

$$\frac{69000\ D^{\frac{11}{4}}\ F^{\frac{1}{2}}}{45000\ D^{\frac{11}{4}}\ F^{\frac{1}{2}}} = 1.533$$

DETAILS OF EXPERIMENTS UPON THE PRESSURE OF THE CHIP ON THE TOOL IN CUTTING STEEL WITH OUR STANDARD TOOLS WITH VARIOUS FEEDS AND DEPTHS OF CUT

566 The following are the general conclusions arrived at on this subject:

567 (A) The total pressure of the chip on the tool in cutting steel of the different qualities experimented upon by us varies between the low limit of 92 tons (2000 lbs.) per square inch of sectional area of the chip, and the high limit of 168 tons (2000 lbs.) per square inch sectional area of the chip. (See Folder 12, Table 81)

568 (B) In cutting the same piece of steel, the pressure of the chip on the tool per square inch of sectional area of the chip grows very slightly greater as the chip becomes thinner, and is practically the same whether the cut is deep or shallow. See Folder 14, Table 99, from which are taken the following typical cases illustrating the relative pressures of a thin feed on the one hand and a coarse feed on the other.

Depth of cut $\frac{3}{16}$ inch $\times$ feed 0.0156 inch: Total pressure per sq. in. sectional area of chip, 295000

Depth of cut $\frac{3}{16}$ inch $\times$ feed 0.125 inch: Total pressure per sq. in. sectional area of chip 257000

569 (C) The same fact mathematically expressed is that in cutting the same piece of steel, the pressure of the chip on the tool per square inch of sectional area of the chip grows greater as the thickness of the chip grows less in proportion to (thickness of the feed)$^{\frac{1}{15}}$ or $F^{\frac{1}{15}}$. (See formula on Folder 14)

The pressure of the chip is in direct proportion to the depth of the cut.

570 (D) Within the limits of cutting speed in common use, the pressure of the chip upon the tool is the same whether fast or slow cutting speeds are used. (See paragraph 576)

571 (E) The pressure of the chip upon the tool depends but little upon the hardness or softness of the steel being cut, but increases as the quality of the steel grows finer. In other words, high grades of steel, whether soft or hard, give greater pressures on the tool than are given by inferior qualities of steel. (See paragraphs 503 and 511)

572 (F) The pressure of the chip on the tool per square inch of sectional area of the chip depends both upon the tensile strength of the steel and its percentage of stretch, and increases both as the tensile strength and stretch increase; although a higher tensile strength has more effect than a large percentage of stretch in increasing the pressure. (See paragraphs 573 to 575)

573 Referring again to Folder 12, Table 81, upon the first, third and fourth horizontal lines of this table will be found data of three steel forgings, which are copied beneath in the order mentioned:

TENSILE STRENGTH IN TONS (2000 LBS.) PER SQUARE INCH	PERCENTAGE OF STRENGTH	PRESSURE ON THE CHIP TONS (2000 LBS.)	CUTTING SPEED IN FEET PER MINUTE
30	29	128	111
35	30	138	64
52	14	168	41

574 It will be noted that the percentage of stretch of the first and

second of these forgings is about the same, whereas an increase of from 30 to 35 tons in the tensile strength of the metal is accompanied by an increase of from 128 to 138 tons pressure on the chip, showing an increase in the pressure on the chip with an increase of tensile strength.

575 Now, on comparing the hard forging, namely, the third on the list, it will be noted that as far as fineness of quality of metal is concerned, its physical tests show it to be about equal to that of the forging on the second line. It will be noted, however, that, as before pointed out, an increase in the percentage of stretch and an increase in the tensile strength both tend toward heavier pressures per square inch of sectional area of the chip upon the tool. By comparing the forgings on the second and third lines, however, it will be seen that an increase from 14 per cent to 30 per cent in the stretch has less effect upon the pressure on the tool than an increase from 35 tons to 52 tons in the tensile strength; thus making it clear that an increase in tensile strength has a greater effect upon the pressure of the chip on the tool than an increase in stretch. A further explanation of this fact will be found in paragraphs 508 to 511.

PRESSURE OF CHIP ON TOOL THE SAME WHETHER FAST OR SLOW CUTTING SPEEDS ARE USED

576 On Folder 14, Table 99, will be noted two sets of pressure experiments made upon steel of the same quality and with tools of the same shape, one set with cutting speeds of 30 feet per minute and another set with cutting speeds of 60 feet per minute. An inspection of the corresponding figures in these two sets of experiments and an examination of Folder 14, Figs. 94 and 95, in which the same data are shown graphically, will indicate that, in general, doubling the cutting speed has no appreciable effect upon the pressure of the tool.

577 This is in substantial agreement with the results obtained in the Manchester experiments. Dr. Nicolson, in one set of dynamometer experiments, made with the same tool and the same piece of steel, obtained increasingly lower pressures on the tool for increases in the cutting speed.

578 On Folder 14, Fig. 93, we reproduce Fig. 342, taken from Dr. Nicolson's paper (published in Transactions, Vol. 25, p. 675).

579 In these experiments a feed of $\frac{1}{8}$ inch and a depth of cut of 0.35 inch was used. It will be observed that at normal cutting speeds there is a very slight diminution of pressures as the speed grows more

rapid. In considering these experiments, however, the cut which was taken at 84 feet per minute should be left out, as in this case the cutting speed was so high that the tool was ruined in one minute and twelve seconds. It is, therefore, evident that this condition is so far from that of normal daily practice that it should not be considered in formulating a law. It will be noted also that at 60 feet cutting speed there are two experiments slightly at variance with the general trend of the rest of the data. On the whole, in these experiments there is close agreement between Dr. Nicolson's observations and our own.

580 As heretofore stated, owing to the voluminous nature of this paper, we shall not treat of the important subject of drilling or boring metals. We would, however, refer to a very elaborate and careful series of experiments by M. Codron published in "Bulletin de La Société D'Encouragement pour L'Industrie Nationale, 1903," probably the most elaborate series of experiments on drilling, boring and trepanning that have yet been published. M. Codron's experiments cover the pressures required to cut not only steels of various hardnesses, but also cast iron, bronze and other metals, and are made on almost all points with the thoroughness characterizing the work of all of our best modern French scientists.

POWER REQUIRED TO FEED THE TOOL

581 By far the most important conclusion arrived at by us in the field of "Pressure of the Chip on the Tool" is that the gearing designed in lathes, boring mills, etc., for feeding the tool should be sufficiently strong to deliver at the nose of the tool A FEEDING PRESSURE EQUAL TO THE ENTIRE DRIVING PRESSURE OF THE CHIP UPON THE LIP SURFACE OF THE TOOL. This fact was developed by us in an experiment made in the year 1883 in the works of the Midvale Steel Company, and had such an important bearing upon the cost of turning out the product in the machine shop of those works that the results of this one simple investigation more than paid for all the experiments in the entire field of cutting metals undertaken in the Midvale Steel Works.

582 All of the lathes, boring mills, etc., purchased by this company from that time forward were fitted with feed gearing designed with power equal to the driving power of the machine, and in this way the many stoppages and delays so common in the average machine shop, due to broken feed gearing, were avoided. What is of even much greater importance, a lack of strength in the feed gearing never was accepted as an excuse on the part of any machinist for not taking the maximum cut on his machine.

583 When, fifteen years later, the writer started to reorganize the management of the Bethlehem Steel Company (a company in direct competition with the Midvale Steel Works and turning out a similar product), he was astounded to find that some of the leading tool builders of the United States who had been supplying extra strong feed motions with the machine tools furnished during this term of years to the Midvale Company, were selling machines fitted with far weaker feed gearing to the Bethlehem Company. On inquiring into the reason for this, he was informed that these tool builders had not even told the Bethlehem Company of the existence of lathes designed with extra heavy gearing, their reason being that they were certain that the Bethlehem Company would not be willing to pay any extra price for the more powerful feed gearing and it would only make them dissatisfied if they knew that they were not getting the most powerful machine built. The introduction of "task management" into the Bethlehem Steel Company, however, promptly developed the weakness in this particular of most of the machine tools in their shop.

584 In justice to one of the greatest engineers in this country, it should be said that all of the special machines designed under the supervision of Mr. John Fritz for the Bethlehem Steel Company were provided with feeding mechanism of ample power. The writer does not recall a single instance in which the feed motions of any of Mr. Fritz's machines broke when they were used to their maximum capacity under task management.

APPARATUS FOR DETERMINING THE POWER REQUIRED TO FEED A TOOL

585 The following very simple apparatus was used in 1883 in our experiments upon the power required to feed the tool. On Folder 9, Fig. 52, will be seen a view of the vertical slide of a Wm. Sellers & Co. 84-inch diameter vertical boring mill. Upon the top surface of this vertical slide a wooden lever was made to bear upon a knife edge, the short end of the lever being held down by a chain connected with an I-bolt, and at the long end of the lever a receptacle was suspended into which weights were added until the required feeding force was obtained. The vertical slide was at first fed by means of its usual feeding screw. A loose washer, however, was fitted beneath the nut of this screw, and this was of course kept tight while the operation of feeding was performed with the regular feed gearing, and weights were added on the end of the wooden lever until the feeding was done by means of the lever instead of by the regular feed mechanism. The point at which this transfer of the feed took place

was determined by finding when the washer just became loose. This was found to be quite a sensitive indication of the power required to feed.

586 The experiments were made upon a locomotive tire, the metal of which was about carbon 0.56 per cent, manganese 0.68 per cent, tensile strength 124,000 pounds, and 12 per cent to 14 per cent of stretch.

587 Tools with cutting edges varying from a straight edge at right angles to the direction of the feed to our standard round nosed tools, approximately, as illustrated in Folder 5, Fig. 24, were used, with a depth of cut varying from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, and the thickness of the feed varying from 0.0243 inch to 0.0774 inch. The pressure required to feed a square nosed tool was somewhat lighter than that required to feed our standard round nosed tool, and under average conditions as to the dullness of the tool, after eliminating the friction of the slide to which the tool was attached, the pressure upon the lip surface of the tool was found to be about 2.2 times the power required to feed the tool.

588 It should be noted, however, that the words "tool of average dullness" have a different meaning in our case from the same term as applied to tools in the average machine shop, since, as pointed out in paragraphs 189 and 197, it was our regular practice to use tools much duller on the average than those in common use in other shops. We ran at such relatively high cutting speeds that the cutting edges of our tools were soon rounded over, and this undoubtedly produced higher feeding pressures than would be required for the ordinary sharp lathe tool.

589 However, before finishing our experiments it occurred to us that the normal power required to feed the tool was not the figure which should be used in designing machine tools, but that the maximum power which would ever be likely to be called for in feeding the tool was the only one to be used practically. This led to an experiment in which an exceedingly dull tool was used, such a tool as would only be allowed by a very careless machinist to continue under cut, but which condition was sooner or later sure to arise in the case of every machine tool throughout the shop.

590 The use just once of a scandalously dull tool in a machine would of course suffice to smash the feed gearing. An experiment made with a tool of this kind demonstrated the fact that to insure against breakage sufficient strength was called for in the feed gears to deliver at the nose of the tool a pressure equal to the total driving pressure of the chip upon the tool.

591 This one almost brutal experiment rendered all our more careful and accurate experiments of merely trifling interest.

592 When in 1904, the thoroughly scientific work of Dr. Nicolson in this field with his lathe tool dynamometer was published, it was with no little interest that we read his paper, feeling that in the end he was doomed to the same disappointment as to much of the scientific value of his work as we had experienced from ours. Unfortunately however, Dr. Nicolson's experiments were not extended to a scandalously dull tool, and for that reason readers of his paper must be warned against the adoption in tool design of the figures on feeding (or "traversing") pressure obtained by him. We do not of course state that the data in Dr. Nicolson's paper were not of great scientific interest, but merely that for the one perhaps most important purpose for which the experiments were undertaken his data should be disregarded.

COOLING THE TOOL WITH HEAVY STREAM OF WATER

EFFECT UPON THE CUTTING SPEED OF POURING A HEAVY STREAM OF WATER UPON THE CUTTING EDGE OF THE TOOL

593 Cooling the nose of a tool by throwing a heavy stream of water or other fluid directly upon the chip at the point where it is being removed by the tool from the steel forging enables the operator to increase his cutting speed about 40 per cent.[1] The economy realized through this simple expedient is so large that it is a matter of the greatest surprise that experimenters on the art of cutting metals have entirely overlooked this source of gain. So far as the writer is aware, no experiments upon this subject have as yet been published. As explained in paragraph 35 (Part 1), in spite of the fact that (as a result of our experiments) the whole machine shop of the Midvale Steel Company was especially designed as long ago as 1893 for the use of a heavy stream of water (super-saturated with soda to prevent rusting) upon each cutting tool, until very recently practically no other shops in this country have been similarly equipped.

594 When one appreciates the very small gain in cutting speed, amounting perhaps to from 2 to 5 per cent, attained by the many experiments which have been made upon the exact angles to

[1] See paragraphs 628 and 629 describing experiment made since writing this section of the paper

which tools should be ground, and also the small practical results realized from experiments upon the pressure of the chip on the tool, and when one realizes the large amount of time and expensive apparatus entailed in these experiments; and, on the other hand, the extreme simplicity of making experiments on the effect of cooling the tool, and the 40 per cent of gain from this source, it is indeed a matter of wonder that this element has been entirely neglected.

595 The following are the important conclusions arrived at as to the effect on the cutting speed of cooling the tool with a heavy stream of water.

596 (A) On Folder 15, Table 110, are summarized the results of our experiments upon the gain in cutting speed through the use of a heavy stream of water on the tool in cutting different qualities of metals with varying types of tools, namely, modern high speed chromium-tungsten tools, heated to the melting point, the old fashioned self-hardening tools, and carbon tempered tools.

597 The results obtained with modern high speed tools are the only ones of great practical interest at present, since no well managed machine shop would use any other than high speed cutting tools. The other data, however, are given as a matter of record and historic interest. (See paragraph 631)

598 (B) With high speed tools a gain of 40 per cent[1] can be made in cutting steel or wrought iron by throwing in the most advantageous manner a heavy stream of water upon the tool.

599 In designing slide rules or tables, etc., for assigning daily tasks to machinists a 33 per cent increase in cutting steel or wrought iron should be allowed for instead of 40 per cent, owing to the fact that workmen are more or less careless in directing the stream of water to the proper spot upon the tool.

600 (C) A heavy stream of water (3 gallons per minute) for a 2-inch by 2½-inch tool and a smaller quantity as the tool grows smaller, should be thrown directly upon the chip at the point where it is being removed from the forging by the tool. Water thrown upon any other part of the tool or the forging is much less efficient. (See paragraphs 607 to 609)

601 (D) The gain in cutting speed through the use of water on the tool is practically the same for all qualities of steel from the softest to the hardest. (See Folder 15, Table 110)

602 (E) The percentage of gain in cutting speed through the use of water on the tool is practically the same whether thin or thick chips are being removed by the tool. (See paragraph 630)

603 (F) With modern high speed tools a gain of 16 per cent can

be made by throwing a heavy stream of water on the chip in cutting CAST IRON. (See paragraphs 625 to 627)

604 (G) To get the proper economy from the use of water in cooling the tool, the machine shop should be especially designed and the machine tools especially set with a view to the proper and convenient use of water. (See paragraphs 610 to 616)

605 (H) In cutting steel, the better the quality of tool steel, the greater the percentage of gain through the use of a heavy stream of water thrown directly upon the chip at the point where it is being removed from the forging by the tool. The gain for the different types of tools in cutting steel is:

a Modern high speed tools 40 per cent;
b Old style self-hardening tools 33 per cent;
c Carbon tempered tools 25 per cent.

606 This fact, stated in different form, is that: The hotter the nose of the tool becomes through the friction of the chip, the greater is the percentage of gain through the use of water on the tool. (See Folder 15, Table 110 and paragraph 631)

THE PORTION OF THE TOOL ON WHICH THE WATER JET SHOULD BE THROWN

607 A series of experiments has demonstrated that water thrown directly upon the chip at the point where it is being removed from the forging by the tool will give higher cutting speeds than if used in any other way.

608 As another illustration of the small value to be attached to theories which have not been proved, we would cite the following: After deciding to try experiments upon the cooling effect of water when used upon a tool, it was our judgment that if a stream of water were thrown upward between the clearance flank of the tool and the forging itself in this way the water would reach almost to the cutting edge of the tool at the part where it most requires cooling, and that, by this means the maximum cooling effect of the water would be realized. We, therefore, arranged for a strong water jet to be thrown, as shown on Folder 7, Fig. 40b, between the clearance flank of the tool and the flank of the forging, and made a series of experiments to determine the cooling effect of water with various feeds and depths of cut. So confident were we of the truth of this theory that we did not deem it worth while to experiment with throwing streams of water in any other way, until months afterward, when upon throwing a stream of water upon the chip directly at the point where it is being removed

from the forging by the tool, we found a material increase in the cutting speed, and thus our first experiments were rendered valueless.

609 Practically, great difficulty will be found in getting machinists in the average shop to direct the stream of water on to the chip in the proper way as indicated on Folder 7, Fig. 40a, because when a sufficiently heavy stream of water is thrown upon the work at this point it splashes much more than when thrown upon the forging just above the chip; and the machinists prefer slower cutting speeds and less splash. However, when they are managed under the "task system" with trained speed bosses who are accustomed to obeying orders, this trouble disappears.

FORTY PER CENT GAIN IN CUTTING SPEED FROM THROWING A HEAVY STREAM OF WATER UPON THE TOOL IN CUTTING STEEL

610 It has been customary for many years to use under certain circumstances, a small trickling stream of water upon cutting tools (mostly on finishing tools, and with the object of giving the work what is called a "water finish"). For this purpose a small water can is generally mounted upon the saddle of the machine above the tool, and refilled from time to time by the machinist. Such streams of water, however, have little or no effect in increasing the cutting speed because they are too small in volume to appreciably cool the nose of the tool.

611 The most satisfactory results are obtained from a stream of water falling at rather slow velocity, but with large volume, at the proper point upon the tool; since a stream of this sort covers a larger area of the tool and is much freer from splash.

612 This water supply should be delivered through pipes fitted up with universal friction joints, so that the apparatus can be quickly adjusted to deliver the water at any desired point (the pipe being supported by a rigid bracket attached to the saddle of the lathe, preferably on the back side so as to be out of the way). In the case of short lathe beds the water supply can be delivered from overhead through a rubber hose, and in the case of long lathe beds through telescoping pipes attached to the saddle (smooth drawn brass pipes telescoping inside of ordinary wrought iron pipes, with suitable stuffing boxes being used).

613 About three gallons of water per minute are required for adequately cooling a very large roughing tool, say, 2 inches by 2½ inches section; and proportionally smaller quantities as the tool grows smaller.

614 For economy, the same water should be used over and over again, and it should be supersaturated with soda to prevent the machines from rusting. Wrought iron pipes about 1¼ inches diameter should lead the water from beneath the machine below the floor to the main soda water drains at the side of the shop. These drains are made of pipe from 3½ to 5 inches in diameter, with a chain extending through them from one end to the other, the chain being twice as long as the drain through which it extends. In case of sediment forming in this pipe or in case of chips passing by the double sets of screens and double settling pots which should be supplied at each machine, the drain can be quickly cleaned by pulling the chain backward and forward through it once or twice.

615 The soda water is returned through this system of underground piping to a large central underground tank, from which it is pumped through a small, positive, continuously running pump, driven by the main line of shafting, into an overhead tank with overflow which keeps the overhead soda water supply mains continually filled and under a uniform head. If the shop is constructed with a concrete floor, a catch basin for the water can be molded in the concrete directly beneath each machine. Otherwise, each machine should be set in a large wrought iron pan or shallow receptacle which catches the soda water and the chips. In both cases, however, two successive settling pots—independently screened so as to prevent the chips, as far as possible, from getting into the return main—are required beneath each machine.

616 The ends of the 1¼ inch wrought iron pipes which lead the water from the machines to a large drain at the side of the shop should be curved up with a sweeping curve so that their outer ends come close to the top of the floor of the shop. The sediment and chips must be cleaned from these pipes from time to time by means of a long round steel rod from ⅜ to ½ inch in diameter, which, after removing the plug at the outer end of the drain pipes, is shoved through the pipe. Apparatus of this type has been in successful use for about 23 years with no trouble from clogging.

DETAILS OF TYPICAL EXPERIMENT FOR DETERMINING GAIN THROUGH HEAVY STREAM OF WATER ON THE TOOL

617 The following is a detailed description of one of our series of experiments on the effect of water on the tool, made in this case for the purpose of determining the gain from the use of a heavy stream of water in cutting an exceedingly hard bar of metal, especially made

and hammer hardened so as to be harder than hard steel of any of the qualities usually met with in machine shop practice. This experiment is given in detail as a type of our best method of experimenting in cases of this kind. The following are the physical tests and the chemical composition of the steel bar experimented upon.

EXPERIMENT BEGAN NOVEMBER 23, 1899

TENSILE STRENGTH	ELASTIC LIMIT	EXTENSION	CONTRACTION	APPEARANCE OF FRACTURE
LBS. 102,270	71,590	PER CENT 1.00	PER CENT 0.75	CRYSTALLINE

CARBON PER CENT	SILICON PER CENT	MANGANESE PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT
1.05	0.147	0.86	0.027	0.034

This bar was hammer hardened.

618 Tools of the shape shown on Folder 5, Fig. 24, were made from tool steel of the following chemical composition, and were treated by the Taylor-White process (*i. e.*, heated to the melting point, cooled down, and reheated to 1150 degrees in a lead bath):

TUNGSTEN PER CENT	CHROMIUM PER CENT	CARBON PER CENT	MANGANESE PER CENT	SILICON PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT
8.00	3.90	1.90	0.30	0.20	0.025	0.030

These tools were marked respectively V_1, V_2, U_3, U_4, U_5. They were then all standardized to prove their uniformity by being run at a cutting speed of 16 feet per minute, duration of cut 20 minutes, feed $\frac{1}{8}$ inch, depth of cut $\frac{3}{16}$ inch. The ruining speed upon this forging of tools of this type had been previously proved to be between 16 and 18 feet per minute. The following are the details of the experiment with water:

EXPERIMENTS WITH WATER

TEST NUMBER	MARK ON TOOL	CUTTING SPEED FEET	DURATION OF CUT MINUTES	CONDITION OF TOOL AT END OF RUN
266 b	V_1	19	20	fair
267 b	V_2	20	20	fair
268 b	U_3	21	20	fair
269 b	U_4	22	20	good
260 b	U_6	23	20	fair
261 b	V_1	24	2	ruined
262 b	U_3	23	1½	ruined
263 b	U_4	23	15½	ruined
264 b	V_2	22	7	ruined
265 b	U_3	22	20	nearly ruined
265 b	V_1	22	15	ruined
267 b	V_1	21	17½	ruined
268 b	V_2	21	20	nearly ruined
269 b	U_6	24	4	ruined
270 b	U_3	20	2½	ruined
271 b	V_1	20	20	nearly ruined

619 From the list given above are below extracted those experiments that show the highest speed at which each tool endured 20 minutes and also the length of time it endured before ruining at one foot higher speed.

TEST NUMBER	MARK ON TOOL	CUTTING SPEED PER MINUTE FEET	DURATION OF CUT MINUTES
271 b	V_1	20	20
267 b		21	17½
268 b	V_2	21	20
264 b		22	7
265 b	U	22	20
262 b		23	1½
259 b	U_4	22	20
263 b		23	15½
260 b	U_6	23	20
296 b		24	4

EXPERIMENTS WITH WATER

620 In test No. 261 b tool V_1 had been ruined at a speed of 24 feet and thereby, owing undoubtedly to being overheated by the friction of the chip, as was afterward ascertained, suffered a marked deterioration. This accounts for the lower maximum speed at which it subsequently stood up.

621 In order to fully ascertain whether the ruining of these tools while running with a heavy stream of water to try to keep them cool had any marked injurious effect upon them, the following tests were made without the use of water on the second day of the experiments:

TOOL NO.	MARK ON TOOL	CUTTING SPEED MINUTES	DURATION OF CUT MINUTES	CONDITION OF TOOL AT END OF RUN
272 b	U_4	16	20	nearly ruined
273 b	U_3	16	20	fair
274 b	U_5	16	20	fair
275 b	V_2	16	less than 20	ruined*
276 b	V_1	14	less than 20	ruined*
277 b	V_3	14	less than 20	ruined*

* Tools V_1 and V_2 had evidently suffered considerably, due to their ruining tests while finding their proper speeds under water, and ought therefore to be left out of consideration. As the V_1 and V_2 tools had evidently been injured during their test with water, the results obtained were not taken in the average.

622 The average cutting speeds of the U tools (all of which were proved to be uninjured) were as follows:

$$\frac{22 + 22 + 23}{3} = 22.33 \text{ feet},$$

which divided by 16 feet gives 1.416 to 1.0 as the gain made by using water on the tool.

623 A similar experiment to the above was made upon a steel bar of about the following chemical composition and physical qualities and annealed at 1300 degrees Fahr.:

CARBON PER CENT	MANGANESE PER CENT	SILICON PER CENT	SULPHUR PER CENT	PHOSPHORUS PER CENT
.34	.54	.176	.026	.037

TENSILE STRENGTH POUND	ELASTIC LIMIT POUND	PERCENTAGE OF STRETCH PER CENT	PERCENTAGE OF CONTRACTION OF AREA PER CENT
70,000	34,000	29	44

624 Taylor-White tools similar to those described above, having been carefully standardized, showed a cutting speed when run without water of 60 feet per minute, and when run under a heavy stream of water of 83 feet, thus indicating a gain of 1.39 to 1.0 from the use of water. The average gain then through the use of water on the tool for hard and soft forgings is about 40 per cent.

SIXTEEN PER CENT GAIN IN CUTTING SPEED FROM THROWING A HEAVY STREAM OF WATER UPON THE TOOL IN CUTTING CAST IRON

625 In 1906 after the writing of this paper was well under way it occurred to us that we had accepted as true without verification through accurate experiments the fact that water could not be used in cutting cast iron. This is another of the many instances in which an absolutely erroneous opinion prevails throughout all of our machine shops without any foundation in fact. It is likely, however, that this opinion has become so firmly rooted in the minds of all mechanics and foremen from the fact that a water finish cannot be made on cast iron, while it is in many cases most desirable for steel.

626 To determine the effect of a heavy stream of water in cooling a tool cutting cast iron, experiments (similar to those described above) were made by us during the summer and fall of 1906 on a test piece consisting of exceedingly hard cast iron with cutting tools of three different chemical compositions. The piece of cast iron is the same as that marked "hard cast iron" on Folder 20, Table 138.

627 The chemical composition of three of the latest high speed tools experimented with was that of tools Nos. 2, 5 and 7 (Folder 20, Table 138). The following table represents the average gain made by these tools when they were run with a heavy stream of water as compared with running under exactly the same conditions dry. Depth of cut $\frac{3}{16}$ inch, feed $\frac{1}{16}$ inch, standard 20-minute cut; tools used, our standard $\frac{7}{8}$ inch (shown Folder 5, Fig. 24)

Cutting speed without water	47 ft.
Cutting speed with heavy stream of water	54 ft. 7 ins.
Gain through use of water	16 per cent

628 Since writing the section of the paper covering the whole subject of the gain by cooling the tool with water, we have again met in our experiments with one of the strange anomalies which characterize the laws governing the art of cutting metals.

629 When the best of the modern high speed tools, namely, tool No. 1, Folder 20, Table 138, was run with a heavy stream of water in cutting the hard forging referred to in the same table, it was shown that instead of a gain of 41 per cent through the use of water, as had been obtained with tools differing in their chemical composition, as referred to in paragraphs 610 to 630, there was a gain through the use of water of only 15 per cent. A lack of time prevented our going more fully into the effect of water upon high speed steels of the most modern composition with medium and soft forgings. It is, therefore, mani-

festly of the greatest importance to carry on thorough experiments in this field. Our experiments with tool No. 1 gave the following data:

Depth of Cut $\frac{3}{16}$ Inch. Feed $\frac{1}{16}$ Inch. Standard 20-minute cut.

Cutting speed without water ..... 41 ft. 5 in.
Cutting speed with water ..... 47 ft. 8 in.
Gain through use of water ..... .15 per cent

THE PERCENTAGE OF GAIN THE SAME WHETHER THIN OR THICK CHIPS ARE BEING REMOVED

630 When in the Midvale Steel Works the gain in cutting speed through the use of water on the tool was discovered in 1884, a thorough investigation was made with varying depths of cut and thickness of feed—carbon tempered tools being used in cutting steel tires—and it was found that the percentage of gain in cutting speed through the use of water was the same whether the chips were thick or thin. These experiments have not been repeated by us with high speed tools, and it is possible that, owing to the very great difference in the heat of the high speed and the carbon tempered tools, there is a different ratio of gain for thick and thin chips with high speed tools. However, our slide rules have been in practical use in cutting chips of all degrees of thickness for years, using water on the tool, with the same ratio of increase in speed for thick and thin chips; and it would seem if any material difference exists between the gain in thick and thin chips, that this fact would have become evident through the failure of our slide rules to indicate the proper speeds. A careful experiment on this point is desirable.

631 In 1894–95 experiments were made with a carbon tempered tool containing 1.6 per cent chromium and with tools made from old fashioned self-hardening Midvale steel, of the following chemical composition:

	CARBON PER CENT	SILICON PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT	MANGANESE PER CENT	CHROMIUM PER CENT	TUNGSTEN PER CENT
MIDVALE	1.143	0.246	0.023	0.008	0.180	1.880	7.723

632 The carbon tempered tools showed an average gain of 25 per cent in cutting a hard steel forging of the following physical and chemical properties:

TENSILE STRENGTH POUNDS	ELASTIC LIMIT POUNDS	STRETCH PER CENT	CONTRACTION OF AREA PER CENT
115,000	58,000	15.6	31.4

CARBON PER CENT	SILICON PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT	MANGANESE PER CENT	COPPER PER CENT
.555	.236	.049	.031	.981	.058

The Mushet and Midvale self-hardening tools showed an average gain of 30 per cent in cutting the same forging. From these figures it will be noted that as the cutting speeds of tools grow higher, the percentage of gain through the use of water for cooling the tool grows greater. This would seem to be due to the fact that (taking the two extremes) the noses of the modern high speed tools are very much hotter under the great friction caused by the high speed of the chip than are the old fashioned tempered tools with their slow speeds, and that therefore the water acts in a considerably more efficient manner in cooling the high speed tools than the slow speed tools.

CHATTER OF THE TOOL

633 The following are the general conclusions arrived at on the subject of chatter of the tool:

CHATTER CAUSED BY THE NATURE OF THE WORK

634 (A) Chatter is the most obscure and delicate of all problems facing the machinist, and in the case of castings and forgings of miscellaneous shapes probably no rules or formulæ can be devised which will accurately guide the machinist in taking the maximum cuts and speeds possible without producing chatter. (See paragraph 648)

635 (B) It is economical to use a steady rest in turning any piece of cylindrical work whose length is more than twelve times its diameter. (See paragraph 669)

CHATTER CAUSED BY THE METHOD OF DRIVING THE WORK

636 (C) Too small lathe-dogs or clamps or an imperfect bearing at the points at which the clamps are driven by face plate produce vibration. (See paragraph 659)

CHATTER CAUSED BY CUTTING TOOLS

637 (D) To avoid chatter, tools should have cutting edges with curved outlines and the radius of curvature of the cutting edge should

be small in proportion as the work to be operated on is small. The reason for this is that the tendency of chatter is much greater when the chip is uniform in thickness throughout, and that tools with curved cutting edges produce chips which vary in thickness, while those with straight cutting edges produce chips uniform in thickness. (See paragraph 661)

638 (E) Chatter can be avoided, even in tools with straight cutting edges by using two or more tools at the same time in the same machine. (See paragraphs 664 and 665)

639 (F) The bottom of the tool should have a true, solid bearing on the tool support which should extend forward almost directly beneath the cutting edge. (See paragraph 663)

640 (G) The body of the tool should be greater in depth than its width. (See paragraph 662)

CHATTER CONNECTED WITH THE DESIGN OF THE MACHINE

641 Chatter caused by modifications in the machine may be classified as follows:

642 (*H*) It is sometimes caused by badly made or fitted gears.

643 (*J*) Shafts may be too small in diameter or too great in length.

644 (*K*) Loose fits in the bearings and slides may occasion chatter.

645 (*L*) In order to absorb vibrations caused by high speeds, machine parts should be massive far beyond the metal required for strength. (See paragraph 656)

THE EFFECT OF CHATTER UPON THE CUTTING SPEED OF THE TOOL

646 (*M*) Chatter of the tool necessitates cutting speeds from 10 to 15 per cent slower than those taken without chatter, whether tools are run with or without water. (See paragraphs 671 to 677)

647 (*N*) Higher cutting speed can be used with an intermittent cut than with a steady cut. (See paragraphs 678 to 680)

648 Of all the difficulties met with by a machinist in cutting metals, the causes for the chatter of the tool are perhaps the most obscure and difficult to ascertain, and in many cases the remedy is only to be found after trying (almost at random) half a dozen expedients.

649 This paper is chiefly concerned with chatter as it is produced or modified by the cutting tool itself. Some of the other causes for chatter, however, may be briefly referred to. These may be divided into five groups:

(A) The design of the machine;
(B) the nature and proportions of the work being operated upon;
(C) the care and adjustment of the parts of the machine;
(D) the method of setting the work in the machine or of driving it;
(E) the shape of the cutting tools, manner in which they are set in the machine and the speeds at which they are run.

Causes (A) and (B) are outside the control of the machinist. Elements (C), (D) and (E) are or should be to a large extent under the control of the management of the shop.

650 (A) Referring, now, to cause (A), "The design of the machine" the chief elements causing chatter in the design of a machine are:

651 (Aa) Gears which are set out of proper adjustment or the teeth of which are untrue. It should be noted that involute teeth will run smoothly whether their pitch diameters exactly coincide or not, whereas the epicycloidal teeth are almost sure to rattle unless their pitch lines are maintained in their exact proper relations one to the other.

652 (Ab) Chatter is frequently caused through mounting the driving gears upon shafts which are either too small in diameter or too long. A large excess in the diameter of shafts beyond that required for strength is called for in order to avoid torsional deflection which produces chatter.

653 (Ac) Lathe shafts and spindles must of course be very accurately and closely fitted in their bearings, and the caps adjusted so as to avoid all play.

654 (Ad) For heavy work the lathe tail stocks should be fastened to the bed plates with bolts of very large diameter, and should be tightened down with long handled wrenches.

655 (Ae) The lathe bed itself should be exceedingly massive, and should contain far more metal than is required for strength or even to resist ordinary deflections; and the moving tool supports should also be heavy far beyond what is required for strength.

MASSIVE MACHINES NEEDED FOR HIGH SPEEDS

656 Undoubtedly high cutting speeds tend far more than slow speeds toward producing minute and rapid vibrations in all parts of the machine, and these vibrations are best opposed and absorbed by having large masses of metal supporting the cutting tool and the head and tail stocks. It is largely for the purpose of avoiding vibration and

chatter in machines that the high cutting speeds accompanying the modern high speed tools call for a redesigning of our machine tools. While it is true that in many cases a very great gain can be made by merely speeding up a machine originally designed for slow speed tools, this increase in speed almost invariably produces a corresponding increase in the vibration or chatter, and for absorbing this, the lathes and machines of older design are, in many cases, too light throughout.

657 (C) Cause (C) namely, "The care and proper adjustment of the various parts of the machine" is almost entirely under the control of the shop management. It is of course evident that so far as the effect of chatter is concerned, one of the most important causes can be eliminated from the shop by systematically looking after the careful adjustment of all of the working parts of the machine to see that the caps of the bearings are always so adjusted as to have no lost motion and yet not bind, and so that all gibs and wedges for taking up wear upon the various slides are kept adjusted to a snug fit. It is our experience, however, that the adjustment of the various parts of the machine should in no case be left to the machinist who runs his lathe, but that the adjustment and care of machines should be attended to systematically and at regular intervals by the management. In large shops a repair boss with one or two men can be profitably kept steadily occupied with this work. A tickler, however, should be used for reminding the repair boss each day of the adjustment of machines and the overhauling which should be attended to on that day.

658 (D) Cause (D), namely, "The method of setting the work in the machine or of driving it," is in many cases capable of being directly under the control of the machinist.

659 (Da) One of the most frequent causes for chatter lies either in having too light or too springy clamps or lathe dogs fastened to the work for the purpose of driving it, or in having vibration at the point of contact between the lathe dog, and the face plate of the lathe, or the driving bracket which is clamped to it. In heavy work the clamps should be driven at two points on opposite sides of the face plate, and great care should be taken to insure a uniform bearing of the clamps at both of these driving points. Chatter through vibration at this point can frequently be stopped by inserting a piece of leather or thick lead between the clamps and the driving brackets on the face plate; which has the effect both of deadening the vibration and equalizing the pressure between the two outside diameters at which the clamp is driven by the face plate.

660 (Db) A dead center badly adjusted so as to be either too tight or too loose on the center of the work, or any lost motion in the

tail stock of the lathe is such an evident source of chatter that it need not be dwelt upon.

661 (E) Cause (E) namely, "The shape of the cutting tools, the manner in which they are set in the machine and the speeds at which they are run." In paragraphs 312 and 315 we have attempted to explain the effect of a uniform thickness of chip in causing chatter, and have indicated that the proper remedy for this is to use a round nosed tool, which is always accompanied by a chip of uneven thickness.

662 In paragraphs 415 and 425 we have also referred to the desirability of having the body of tools deeper than their width in order to insure strength as well as to diminish the downward deflection of the tool, which frequently results in chatter, particularly when the tools are set with a considerable overhang beyond their bearing in the tool post.

663 In paragraphs 450 and 459 we have also called attention to the great desirability of designing tools with their bottom surfaces extending out almost directly beneath the cutting edge, and of truing up the bottom surface of the tools, so as to have a good bearing directly beneath the nose of the tool on the tool support. If sufficient care is taken in the smith shop and the smith is supplied with a proper surface plate, the tools can be dressed so as to be sufficiently true on their bottom surfaces for all ordinary lathe work.

664 As indicated in paragraphs 315 to 325, it has been the necessity for avoidance of chatter which has influenced us greatly in the adoption of round nosed tools as our standard. As shown in paragraph 312, tools with straight cutting edges, which remove chips uniform throughout in thickness can be run at very much higher cutting speeds than our standard round nosed tools; but owing to the danger of chatter, from these tools, their use is greatly limited, in fact, almost restricted to those speecial cases in which chatter is least likely to occur. Attention should be called, however, to a method by which straight edge tools have been used successfully for many years upon work with which there was a very marked tendency to chatter.

665 While at the works of the Midvale Steel Company we superintended the design of a large lathe for rough turning gun tubes and long steel shafts; in which tools with long straight cutting edges were used without chatter, and yet at the high speeds corresponding to the thin chips which accompany this type of tool. This lathe was designed with saddle and tool posts of special construction, so that two independently adjustable tool supports were mounted on the front side of

the lathe and one on the back side. In each of these slides a heavy straight edge tool was clamped. The three tools were then adjusted so that they all three removed layers of metal of about equal thickness from the forging, and, although the tendency toward chatter,—owing to the uniform thickness of the chip,—as indicated in paragraph 315, was doubtless as great with these straight edge tools as with any others, the period of maximum or of minimum pressure for all three tools never corresponded or synchronized so that when one tool was under maximum pressure, one of the others was likely to be under minimum pressure. For this reason the total pressure of the chips on all three tools remained approximately uniform and chatter from this cause was avoided.

666 (B) Cause (B), namely, "The nature and proportions of the work being operated upon."

667 In assigning daily tasks to each machinist with the help of our slide rules, the element which still continues to give the greatest trouble to the men who write out these instructions is deciding just how heavy a cut can be taken on the lighter and less rigid classes of work without causing chatter. This branch of the art of cutting metals has received less careful and scientific study than perhaps any other. While the element is one which must always remain more or less under the domain of "rule of thumb," since the causes which produce chatter, particularly in castings of irregular shapes, are so many and complicated as to render improbable their successful reduction to general laws or formulæ, undoubtedly much can be done toward attaining a more exact knowledge of this subject, and experiments in this line present a most important field of investigation.

668 The following rule (belonging to the order of "rule of thumb") which has been adopted by us after much careful and systematic observation, extends over work both large and small, and covers a wide range:

IT IS ECONOMICAL TO USE A STEADY REST IN TURNING ANY PIECE OF METAL WHOSE LENGTH IS MORE THAN TWELVE TIMES ITS DIAMETER

669 When the length of a piece becomes greater than twelve times its diameter, it is necessary to reduce the size of the cut to such an extent that more time will be lost through being obliged to use a light cut than is required to properly adjust a steady rest for supporting the piece.

670 There is one cause for chatter which would seem to be impos-

sible to foresee and to guard against in advance; *i. e.*, chatter which is produced by a combination of two or more of the several elements likely to cause chatter. If, for instance, the natural periods for vibration in the tool and in the work or in any of the parts of the lathe and the work happen to coincide or synchronize, then chatter is almost sure to follow; and the only remedy for this form of chatter seems to be in a complete change of cutting conditions; a change, for instance, to a coarser feed with an accompanying slower cutting speed, or vice versa. Unfortunately, for economy, higher speeds rather than slow speeds tend to produce this type of chatter, and the remedy therefore generally involves a slower cutting speed.

THE EFFECT OF CHATTER UPON THE CUTTING SPEED

671 A tool which chatters to any great extent must be run at a rather slower cutting speed than a tool which runs free from chatter, as will be seen by the following carefully tried experiment:

672 A forging, 14 feet long, $4\frac{5}{8}$ inches diameter, made out of exceedingly hard steel which was especially hammer hardened and uniform, was placed in the lathe, and standard cuts $\frac{3}{16}$ inch depth, and $\frac{1}{8}$ inch feed (with our standard round nosed tool $\frac{7}{8}$ inch) were taken upon it in such a way that they first ran smoothly without chattering; other cuts were then taken in such a position on the forging that the tool chattered badly throughout its cut. This was accomplished by using a steady rest in one case so as to prevent chatter, and in the other case running without the steady rest. All of the tools had been carefully standardized before starting the experiments, and proved uniform and capable of running at maximum cutting speeds. The forging had also been proved uniform, and its standard cutting speed had been shown to be between $15\frac{1}{2}$ and 16 feet per minute.

673 In the two tables below in paragraph 674 are given the details of the cutting speeds obtained with and without chatter. In one of these experiments the tool was run without water and in the other the tool was cooled through the use of a heavy stream of water.

674 An examination of the results of this experiment indicates in general that chatter causes a reduction in cutting speed of from 10 per cent to 15 per cent whether tools are run without water or with a heavy stream of water to cool them.

675 The following EXPERIMENTS SHOW THAT CHATTER CAUSES A REDUCTION IN CUTTING SPEED OF 10 PER CENT TO 15 PER CENT WHETHER THE TOOLS ARE RUN WITH OR WITHOUT WATER TO COOL THEM. (See paragraphs 671 to 676)

CHATTER CAUSES REDUCTION 10 TO 15 PER CENT IN CUTTING SPE

NO WATER ON THE TOOL

TEST NO.	MARK ON TOOL	CUTTING SPEED	DURATION OF CUT	CONDITION OF TOOL AT END OF RUN	WHETHER TOOL TERED OR N
		ft. in.	min.		
124 b	U_8	15	20	good	no chatter
125 b	U_8	17 6	14½	ruined	no chatter
126 b	U_8	15	4¾	ruined	chattered bad
127 b	U_8	15	9¾	ruined	chattered bac

WATER ON THE TOOL

TEST NO.	MARK ON TOOL	CUTTING SPEED	DURATION OF CUT	CONDITION OF TOOL AT END OF RUN	WHETHER TOOL TERED OR N
		ft.	min.		
128 b	U_{10}	19	5½	ruined	chattered bac
129 b	U_{10}	19	20	fair	no chatter

676 Experiment No. 125b was made for the purpose of a showing conclusively that both the tool and the forging had properly standardized. It will be noted that this tool, free from c ter, broke down in 14½ minutes at a cutting speed of 17 feet 6 inc whereas the tool just above it ran all right at 15 feet for 20 min showing that both the forging and tools had been properly stand ized.

677 Accurate experiments on the chatter of the tool are diff to make because the comparatively small diameter of work w is needed to insure chatter calls for an extremely hard piece of m (*i. e.*, slow cutting speeds) in order to make the runs, which must for 20 minutes, extend through a sufficiently short distance ove length of the forging so that the tools shall not be in danger of cha ing. It was for this reason that we were obliged to make the a forging out of extremely hard metal.

HIGHER CUTTING SPEED CAN BE USED WITH AN INTERMITTENT THAN WITH A STEADY CUT

678 An intermittent cut, however, has a very different effect cutting speed from that produced by chatter. We have observ a large number of cases that when a tool is used in cutting steel w

y stream of water on it (and this is the proper method of cutting of all qualities), a rather higher cutting speed can be used with ıtermittent cut than with a steady one. The reason for this is during that portion of the time when the tool is not cutting, the r runs directly on those portions of the lip surface and cutting of the tool which do the work and for this reason the tool is more tively cooled with intermittent work than with steady work. As xample of intermittent work, the writer would cite:

a cutting the outside diameter of a steel gear wheel casting, in which case the tool is only one-half its time under cut;

b or turning small pieces of metal which are greatly eccentric;

c or, for example, all planer and shaper work which is not too long.

679 It would seem from a theoretical standpoint that a tool would greatly damaged (and therefore a slow cutting speed would be led for) by the constant series of blows which its cutting edge ives through intermittent work. It will be remembered, however, ıt in planer work (and this class of intermittent work comes to the ect attention of every machinist), the tool is more frequently jured while dragging backward on the reverse stroke of the planer an it is while cutting, and it is very seldom that a tool is damged as it starts to cut on its forward stroke. In all cases, however. here the tool deflects very greatly, when it starts its cut on intermittent work slower speeds are called for than would be required for teady work.

680 The above remarks on intermittent work do not, of course, pply to cast iron with a hard scale or the surface of which is gritty. It is evident that in all such cases owing to the abrasive action of the and or scale on the tool, intermittent work is much more severe upon the tool than a steady cut.

HOW LONG SHOULD A TOOL RUN BEFORE REGRINDING?

THE EFFECT UPON THE CUTTING SPEED OF THE DURATION OF THE CUT; I. E., THE TIME WHICH THE TOOL MUST LAST UNDER PRESSURE OF THE CHIP WITHOUT BEING REGROUND

681 The following are the principal conclusions arrived at on this subject, regarding the duration of the cut:

682 (A) For a practical table showing how long each sized tool

should be run before being reground, see Folder 15, Table 108. (See paragraphs 710 to 728)

683 (B) For reasons for running tool the length of time given in the practical table referred to in Conclusion A, see paragraphs 710 to 717.

684 (C) If we note the proper cutting speed for a tool which is to last 20 minutes, and wish to find the cutting speed for a tool to last 40 minutes, multiply the 20 minute cut by 0.92. (See paragraph 701)

685 (D) If we have the proper cutting speed for a tool to last 20 minutes, and wish to find the proper cutting speed for a tool to last 80 minutes, multiply the 20-minute cut by 0.84. (See paragraph 701.)

686 (E) For a practical table giving the ratios between the cutting speeds corresponding to different durations of cut, see Folder 15, Table 105. (See paragraphs 696 to 704)

687 (F) For formula from which practical table in (A) was made up, see Folder 15, Table 103; diagram 104; and description, paragraph 700.

688 (G) The same relation exists between the duration of the cut and the cutting speed for steels of different degrees of hardness. (See paragraph 705)

689 (H) No scientific or correct conclusions can be drawn from tests in the art of cutting metals in which cuts of much shorter duration than 20 minutes are used. (See paragraphs 703 and 704)

690 (J) We have been unable to accurately determine the relation between the duration of the cut and the cutting speed for tools used in cutting cast iron. Such laws are badly needed. (See paragraph 709)

691 (K) For the relation of the duration of cut to cutting speed when carbon tempered tools are used, see Folder 15, Table 107; diagram 106; paragraphs 706 and 707)

692 (L) Modern high speed tools do a very much larger amount of work without regrinding than carbon tempered tools. The effect upon the cutting speed of the duration of the cut, modern high speed tools and carbon tools compared. (See paragraph 708)

693 In paragraph 149, we have called attention to the fact that as a measure of the value of a tool, the length of time which a tool can be run without being reground is a false and worthless standard; and in paragraphs 177 to 182, we have called particular attention to the radically different kind of wear which occurs with tools that last only a short while under cut and those which last for a longer time.

694 Briefly restated, the reason for this is that in order to have it last a long time, any given tool must be run at so slow a cutting speed

as to waste the time of both the machinist and the machine. The small saving in grinder's wages, in the wages of the smith and in tool steel, which is made by having a tool last a very long time, is much more than overbalanced by the diminished output of the machine which corresponds with the slow cutting speed. So little, however, is the effect of the duration of the cut upon the cutting speed generally understood that probably not one machinist in a thousand realizes that there exist clearly defined laws as to the effect of the duration of the cut on the cutting speed. It is also safe to say that for the purpose of avoiding frequent grinding it is the almost universal practice in machine shops to run tools at cutting speeds which are entirely too slow for maximum economy, when all of the elements bearing upon this subject are properly considered. And indeed this and the various other laws together present a problem which is so complicated that no mechanic or even mathematician can quickly and correctly solve it without the use of slide rules. As stated in paragraphs 113 to 119 even with the slide rules but comparatively small gain will be made unless the older type of management has been superseded by the system of task management with its accompanying aids in the form of functional foremanship, written instructions and its various safeguards.

695 Several series of careful experiments have been made by us at different times to investigate the precise effect of the duration of cut upon the cutting speed. The first of these was made in 1883 at the Midvale Steel Works, with carbon tempered tools, both when the tools were run dry and when they were run under a heavy stream of water. The summary of the results of these experiments will be described in paragraphs 706 and 707.

EFFECT UPON CUTTING SPEED OF DURATION OF CUT, MODERN HIGH SPEED TOOLS BEING USED

696 The only experiments which are of practical interest in this field are those made with modern high speed tools.

697 On Folder 15, Table 103, is given a summary of one set of experiments in which the important details of each tool trial are entered. Underneath each set of trials we give our conclusion as to the correct cutting speed corresponding to the given duration of cut. In these experiments, tools made of the following chemical composition were used:

Tungsten	8.50 per cent
Chromium	2.00 per cent

Carbon..... 1.85 per cent
Manganese..... 0.15 per cent
Silicon..... 0.15 per cent

698 In the test made upon our standard tools, the shapes in cated in Folder 5, Fig. 23, were used, ground to the followi angles:

Clearance, 6 degrees
Back slope, 8 degrees
Side slope, 14 degrees

699 Each tool had previously been standardized upon a forging as uniform steel as we could obtain, so as to prove all of the tools be approximately uniform in their cutting speeds. A test piece annealed steel about 24 inches in diameter and 10 feet long, havi approximately the following chemical composition and the followi physical test was used for making the trial.

CHEMICAL COMPOSITION OF FORGING		PHYSICAL PROPERTIES OF FORGING	
C	0.34	Tensile Strength	[illegible]
Mn	0.60	Elastic Limit	[illegible]
Si	0.183	Per Cent Extension	[illegible]
P	0.035	Per Cent Contraction	[illegible]
Su	0.032		

700 On Folder 15, Fig. 104, are plotted the summarized val given on Folder 15, Table 103, and a curve approximating these val is drawn on the diagrams. This curve is represented by the follow formulæ:

$$V = \frac{90}{T^{\frac{1}{8}}}$$ in which

V = speed of the tool in feet per minute;
T = length of time tool must last without grinding.

701 The data expressed in this formula and by this curve may given also in the following simple form. If we know the proper cu ting speed for a tool which is to last 20 minutes, and we wish to fi the cutting speed for a tool to last 40 minutes, multiply the 20-minu cutting speed by 0.92, and if we have the proper cutting speed for a t to last 20 minutes and we wish to find the proper cutting speed fo tool to last 80 minutes, multiply the 20-minute cutting speed 0.84. (See Folder 15, Table 105)

702 A glance at these figures will show the material gain in cutt speed which can be made by grinding tools every 20 minutes, s instead of grinding them every 80 minutes.

703 It will be noted that in this table and formula we have inclu cuts of as short duration as 10 minutes. It is proper, however,

attention to the fact that the duration of 20 minutes is the shortest ning time from which it is safe to draw any correct scientific con- sions from tests in the art of cutting metals. The reasons for this tement will be found in paragraphs 175 to 182, under the heading "The nature of wear on tools depends upon whether it has been ily caused by heat," and in paragraphs 183–4 under the heading of Reason for adopting the standard test period of 20 minutes."

704 There are certain classes of experiments, however, in which it of great advantage to have even an approximate idea of the relation tween the cutting speed of a tool which gives out in 10 minutes and at of tools which will last through a longer period; and it is for is reason that we have included the 10-minute period in our law; though we wish it distinctly understood that the same value does not ttach to the 10-minute figures as to those corresponding to 20 min- tes duration and upward.

705 We have made a number of experiments upon the effect of the uration of cut on cutting speed with different qualities of steel, and nd that approximately the same relation exists between the duration f cut and cutting speed for steels of different degrees of hardness. his statement, however, does not apply to cast iron. See paragraph 708.

FFECT UPON CUTTING SPEED OF DURATION OF CUT, CARBON TEMPERED TOOLS BEING USED

706 On Folder 15, Table 107, and on Folder 15, Fig. 106, are given he results of a similar experiment tried with carbon tempered tools. The steel which was cut was in this case a large locomotive tire. A practical rule resulting from these experiments is :

707 If we know the proper cutting speed for a tool which is to last 20 minutes, and we wish to find the cutting speed for a tool to last 40 minutes, multiply the 20-minute cutting speed by 0.87 or divide it by 1.15. And if we have the proper cutting speed to last 20 minutes and we wish to find the cutting speed for a tool to last 80 minutes, multiply the 20-minute cutting speed by 0.76 or divide it by 1.32.

FFECT UPON CUTTING SPEED OF DURATION OF CUT, WITH MODERN HIGH SPEED TOOLS AND CARBON TOOLS COMPARED

708 A comparison of the following figures will show that the high peed tools fall off less in their cutting speed than the carbon tools, hen they are run for a long time, since with tempered tools an 80- minute cut is 24 per cent slower than a 20-minute cut, while with

the modern high speed tools an 80-minute cut is only 16 per cent slower. The following table shows the increased durability of the new high speed steels even when they are run at their proper cutting speeds.

	DURATION OF CUT		AN 80-MINUTE CUT IS FOLLOWING PER CENT SLOWER THAN A 20-MINUTE CUT
HIGH SPEED TOOLS, CUTTING SPEED	20 MINUTES	80 MINUTES	
	99 ft. per minute	83 ft. per minute	16 per cent
CARBON TEMPERED TOOLS, CUTTING SPEED	16 ft. per minute	12 ft. per minute	24 per cent

EFFECT UPON CUTTING SPEED OF DURATION OF CUT IN CUTTING CAST IRON

709 We have made several attempts to accurately determine the law governing the effect of the duration of cut upon cutting speeds when tools were used upon cast iron. These experiments have up to date, however, been uniformly unsuccessful, because we have failed to obtain a sufficiently large and uniform body of cast iron to enable us to make the number of tests required for an accurate determination of the law. In general, however, it may be said, that those tests which we have made indicate that tools are even more enduring in cutting cast iron than in cutting steel; *i. e.*, that there is a smaller percentage of falling off in cutting speed between a 20- and an 80-minute cut in cast iron than there is with the corresponding cuts in steel.

710 Perhaps the most important practical decision to be made after studying the laws of the effect of the duration of cut upon the cutting speed, all things considered, is: what is the most economical length of time for running each sized tool before regrinding it?

711 It is clear that we have on the one hand the main fact that the more often we are willing to grind the tool the higher the cutting speed at which the tool can be run, and therefore the larger the amount of work which will be turned out by the machine. On the other hand, there are four opposing considerations all of which tend toward a greater expense the more frequently the tools are ground. These considerations are:

712 (A) The time required to remove the worn-out tool from the tool-post; get another sharp tool; set and clamp it into the tool-post; and again start the roughing cut to exactly the proper size. For exact figures see, Folder 15, Table 108.

713 (B) The time of the tool grinder and the grinding machine and the wear on the emery wheel each time a tool is ground, which can be expressed in terms of the time of the lathe hand and his lathe time. For exact figures see, Folder 15, Fig. 108.

714 (C) The cost of the smith's and helper's wages, and fire, blast, etc., in the smith shop, for dressing a tool; which cost should be divided by the total number of times the tool is ground before it requires redressing. And this fraction of the dressing cost can then be expressed also in terms of the time of the lathe hand and his lathe. For exact figures see, Folder 15, Fig. 108.

715 (D) The cost of the tool steel which is lost every time a tool is redressed. This cost should also be divided by the total number of times the tool is ground, and expressed in terms of the time of the lathe hand and lathe. For exact figures see, Folder 15, Fig. 108.

716 This problem has been put into definite mathematical form and solved by us as follows: Let us assume that the cost of the grinder's wages plus the cost of the grinding machine is the same per hour or minute as the cost of the lathe in which the work is being done plus the wages of the lathe hand for lathes using certain sized tools; and that for lathes using larger sized tools the grinding machine cost is proportionally smaller, while for lathes using smaller tools the grinding machine cost is proportionally larger. Also, in a similar way the cost of the smith and his helper and of the fuel are expressed in terms of the time of the lathe hand and his machine, as stated above. This enables us then to arrive at the following mathematical solution of the problem.

717 Folder 15, Table 108, we have given the time required to dress and grind the various sized tools, and also the time required to place them in the machine, remove them from the machine, and start the cut. These data have been compiled from accurate observations made in each case by a competent observer with a stop watch, while the grinder, the lathe hand, and the smith were working at their proper normal speeds. In the same table we have also given the average number of times that each of the sizes of our standard tools can be reground before requiring to be redressed. The cost of the tool steel used each time a tool is dressed is also found in the same table.

THE MOST ECONOMICAL DURATION OF THE CUT IN CUTTING STEEL

718 In paragraph 700 will be found the following formula for the relation between the cutting speed V and the length of time T that the tool will last before requiring to be reground.

$$V = \frac{90}{T^{\frac{1}{4}}} \qquad [A]$$

The general form of which is:

$$V = \frac{\text{Constant}}{T^{\frac{1}{4}}} = \text{Constant} \times T^{-\frac{1}{4}} \qquad [B]$$

for any given hardness of metal and efficiency of tool.

719 Let t = the sum of the four periods of time $A + B + C + D$ described in paragraphs 716 and 717. Let us then look upon the time t as if it were all time lost or necessarily wasted by the lathe hand and his machine after he has run his tool continuously for T minutes; or, in other words, let us assume that, during a period of $T + t$ minutes the tool will be cutting for T minutes and then give out, and that the machine, as a consequence, will be laid idle during the remaining t minutes.

720 Now, the cutting speed of the tool being V, the quantity or weight of metal W removed (in the total time $T + t$) must be directly proportional to the product VT; that is,

$$W = \text{Constant} \times VT$$

721 Let r = the average rate at which the metal is removed during the whole period $T + t$, then we have

$$r = \frac{W}{T + t} = \text{Constant} \times \frac{VT}{T + t} \qquad [D]$$

722 But we have seen, formula (B), that $V = \text{Constant} \times T^{-\frac{1}{4}}$ which substituted in formula [D] gives

$$r = \text{Constant} \times \frac{\text{Constant} \times T^{-\frac{1}{4}} \times T}{T + t} = \text{Constant} \times \frac{T^{\frac{3}{4}}}{T + t} \qquad [E]$$

723 Let n = the number of times t is contained in T then we have

$$T = nt \qquad [F]$$

and substituting [F] in [E], we have

$$r = \text{Constant} \times \frac{(nt)^{\frac{3}{4}}}{nt + t} = \text{Constant} \times \frac{n^{\frac{3}{4}}\, t^{\frac{3}{4}}}{(n+1)\, t} = \frac{\text{Constant}}{t^{\frac{1}{4}}} \times \frac{n^{\frac{3}{4}}}{n+1} \qquad [G]$$

724 However, for any given tool, t is also a constant, and we finally get from [G]

$$r = C \times \frac{n^{\frac{3}{4}}}{n + 1} \qquad [H]$$

in which C is a complex constant.

725 Assuming successive values for n from o up, we get the owing corresponding values for the expression $\frac{n^{\frac{1}{2}}}{n+1}$, to which the responding values of the rate r are proportional.

n	0	1	2	3	4	5	6	7	8
$\frac{n^{\frac{1}{2}}}{n+1}$	0	0.5000	0.6119	0.6538	0.6728	0.6815	0.6852	0.6862	0.6854
n	9	10	12	15	20	25	30	35	40
$\frac{n^{\frac{1}{2}}}{n+1}$	0.6839	0.6817	0.6766	0.6683	0.6549	0.6432	0.6326	0.6234	0.6152

726 We thus see that the rate r increases very rapidly with n, to gin with; reaches a maximum[1] for $n = 7$, is not far from this maxi- um for n as low as 5, and remains close to this maximum as far as = 10, and even beyond this falls off at a very slow rate only.

727 If we put the value of the maximum rate ($r_m = C \times 0.6862$) ual to 100, we get the following table of the other rates correspond- g to the various values of n in per cent of this maximum rate (for = 7), by multiplying $\frac{100}{0.6862}$ by the various values of $\frac{n^{\frac{1}{2}}}{n+1}$.

n	0	1	2	3	4	5	6	7	8
r cent of Max.	0	72.9	89.1	95.3	98.1	99.3	99.9	100	99.9
n	9	10	12	15	20	25	30	35	40
r cent of Max.	99.7	99.4	98.6	97.4	95.5	93.7	92.2	90.8	89.7

728 This table of rates of removing the metal in per cent of the aximum rate is graphically represented by the diagram on Folder , Fig. 100.

[1] That this rate is a maximum for $n = 7$, and not merely approximately so (which all that can be fully asserted from the inspection of the table), is readily shown differentiating the function, $r = C \times \frac{n^{\frac{1}{2}}}{n+1}$, and finding that value of n for which $\frac{dr}{dn} = 0$; thus

$$dr = C \frac{(n+1)\, dn^{\frac{1}{2}} - n^{\frac{1}{2}} d\,(n+1)}{(n+1)^2}$$

$$= C \frac{(n+1)\, \frac{1}{2} n^{-\frac{1}{2}}.dn - n^{\frac{1}{2}}.dn}{(n+1)^2},$$

d $$\frac{dr}{dn} = C \times \frac{7(n+1) - 8n}{8(n+1)^2 n^{\frac{1}{2}}} = \frac{C}{8(n+1)^2 n^{\frac{1}{2}}} (7 - n),$$

ich becomes 0 for $n = 7$.

EFFECT OF FEED AND DEPTH OF CUT ON CUTTING SPEED

THE EFFECT OF VARYING THE FEED AND THE DEPTH OF THE CUT UPON THE CUTTING SPEED

The following are the principal conclusions arrived at on this subject:

729 (A) With any given depth of cut metal can be removed faster, *i. e.*, more work can be done, by using the combination of a coarse feed with its accompanying slower speed than by using a fine feed with its accompanying higher speed. (See paragraphs 743 to 751)

730 For example, by referring to any of the sets of experiments in cutting steel, described in paragraphs 743 to 772, it will be noted that if with a combination of $\frac{3}{16}$ inch depth of cut and $\frac{1}{64}$ inch feed, the hardness of the metal were of such a quality, for instance, that just 100 pounds of chips would be cut off in an hour by using the same tool on the same forging at its proper cutting speed corresponding to a feed of $\frac{1}{8}$ inch, the metal would then be removed at the rate of 250 pounds per hour. In most cases it is not practicable for the operator to take the coarsest feeds, owing either to the lack of pulling power of the machine or the elasticity of the work. Therefore, the above rule is only of course a broad general statement.

731 (B) The cutting speed is affected more by the thickness of the shaving than by the depth of the cut. (See paragraphs 761 to 763) A change in the thickness of the shaving has about three times as much effect on the cutting speed as a similar or proportional change in the depth of the cut has upon the cutting speed. Dividing the thickness of the shaving by 3 increases the cutting speed 1.8 times, while dividing the length that the shaving bears on the cutting edge by 3 increases the cutting speed 1.27 times. (See paragraphs 303 to 306)

732 (C) Expressed in mathematical terms, the cutting speed varies with our standard round nosed tool approximately in inverse proportion to the square root of the thickness of the shaving or of the feed; *i. e.*, S varies with $1/\sqrt{F}$ approximately. (See the various formulæ from paragraphs 770 to 787)

733 (D) With the best modern high speed tools, varying the feed and the depth of the cut causes the cutting speed to vary in practically the same ratio whether soft or hard metals are being cut. (See paragraphs 1062 and 815 to 828)

734 (E) The same general formula expresses the laws for the effect of depth of cut and feed upon the speed, the constants only

requiring to be changed. (See paragraphs 769 to 770) This is a matter of very great importance, as it enables us to use a single slide rule as a means of finding the proper combination of speed and depth of cut and feed for all qualities of metal which may be cut. (See paragraph 772)

736 (F) The same general type of formula expresses the laws governing the effect of the feed and depth of cut upon the cutting speed when using our different sized standard tools. This is also fortunate as it simplifies mathematical work in the final solution of the speed problem. (See paragraph 772)

IMPORTANCE OF THE STUDY OF EFFECT OF FEED AND DEPTH OF CUT UPON CUTTING SPEED AND THE DIFFICULTIES ATTENDING THESE EXPERIMENTS

737 A study of the effect of the feed and depth of cut upon the cutting speed constitutes in our judgment the most important element in the art of cutting metals. As pointed out in the opening paragraphs of this paper, the three questions which must be answered each day in every machine shop by every machinist who is running a metal cutting machine, such as a lathe, planer, etc., are:

WHAT TOOL SHALL I USE?
WHAT CUTTING SPEED SHALL I USE?
WHAT FEED SHALL I USE?

738 Having already established in a shop standards for the shape and quality of the tools, there remain but two of these questions to be answered, namely, as to the cutting speed and the feed. And the decision as to the cutting speed will depend more upon the depth of cut and feed which are chosen than upon any other element.

739 Experiments upon these two elements can only be undertaken after practically all of the other elements in the art of cutting metals have been standardized. A standard quality of tool steel and its proper heat treatment must have been established. A standard curve for the cutting edge of the tools, with standard lip angles, back slope and side slope, must have been established. The effect of the quality of the metal which is to be cut upon the pressure on the tool and of the pressure on the tool upon the pulling or driving power of the machine must be known before it is possible to decide upon the depth of cut and feed.

740 The depth of cut and feed, then, are of necessity almost the last elements to be experimented upon, and with the exception of determining the combination of the best tool steel and its proper heat

treatment, they constitute the two elements to which we have given the largest amount of time and study. We have undertaken many sets of experiments upon this subject since 1881 when we first began its investigation, and as discussed in paragraph 213 the accurate determination of these laws is rendered especially difficult owing to the necessity for making such a large number of experiments in cutting pieces of test metal which are uniform in quality. We have found it difficult to obtain large enough masses of uniform metal to accurately determine these laws, and each improvement in the quality of the tool steel which gives higher cutting speeds calls for larger and larger masses of uniform test metal, thus greatly increasing the difficulty and expense of these experiments.

741 Moreover, each change in almost any one of our important standards involves in the end a more or less elaborate investigation as to what modification the new standard has made in the effect that a change of feed or depth of cut has upon the cutting speed. Time after time the absolutely necessary changes in standards have forced us to reinvestigate the effect of feed and depth of cut upon cutting speed; and viewed from the point of expense alone, such an investigation is truly a serious undertaking. It is a matter of doubt to the writer whether with our accumulated experience it would be possible even now for us to make a consistent series of experiments either upon steel or cast iron with these two elements at a smaller cost than $5000.

742 All of these facts emphasize the desirability for the greatest care and consideration in adopting shop standards, and indicate the importance of not changing shop standards when once adopted except from imperative necessity.

PRACTICAL TABLES GIVING CUTTING SPEEDS CORRESPONDING TO DIFFERENT DEPTHS OF CUT AND THICKNESS OF FEED ON HARD, MEDIUM AND SOFT STEEL AND ON HARD, MEDIUM AND SOFT CAST IRON, WHEN BEST MODERN HIGH SPEED TOOLS OF OUR STANDARD SHAPES ARE USED

743 Before starting to discuss the experiments upon this subject and the formulæ which we have developed to represent the conclusions drawn from them we give the following:

744 Folder 24, Figs. 143–154, are practical working tables which will be found useful by machine shop foremen and machinists as a general guide to determining what cutting speed to use under several of the usual or typical conditions met with in ordinary machine shop practice. The cutting speeds given in these tables are based upon

the use of our standard tools, shown on Folder 5, Figs. 24 and 28, for cutting hard steel and cast iron, and those shown in Folder 5, Figs. 24 and 20b for cutting medium and soft steel. In making these tables we also assumed the use of the best quality of high speed tool as represented by tool No. 1 (Folder 20, Table 138), treated in the best manner, as described by us in paragraphs 979 to 994. The tables were also based upon cutting three different qualities of steel, having the following chemical and physical properties, and the following cutting speeds when cut with our standard $\frac{7}{8}$ inch tool, $\frac{3}{16} \times \frac{1}{16}$ cut, for standard 20-minute cut.

745 HARD STEEL Cutting speed, 45 ft. per minute; Class No. $21\frac{1}{4}$, (such for instance as is used in a hard locomotive tire)

Carbon	0.64 per cent
Manganese	0.70 per cent
Silicon	0.21 per cent
Phosphorus	0.044 per cent
Tensile strength	118,500 lbs.
Elastic limit	70,000 lbs.
Percentage of stretch	14

746 MEDIUM STEEL Cutting speed, 99 ft. per minute; Class No. 12.

Carbon	0.34 per cent
Manganese	0.60 per cent
Silicon	0.183 per cent
Sulphur	0.032 per cent
Phosphorus	0.035 per cent
Annealing heat,	1275 degrees Fahr.
Tensile strength	72,830 lbs.
Elastic limit	34,630 lbs.
Per cent of stretch	30
Per cent of contraction	48.73

747 SOFT STEEL Cutting speed, 198 ft. per minute; Class No. $5\frac{3}{4}$.

Carbon	0.22 per cent
Manganese	0.42 per cent
Silicon	0.07 per cent
Sulphur	0.025 per cent
Phosphorus	0.022 per cent
Annealing heat,	1200 degrees Fahr.
Tensile strength	56,250 lbs.
Elastic limit	26,590 lbs.
Per cent of stretch	35.50
Per cent of contraction	56.26

751 The tables made out for cutting cast iron are based upon three qualities of cast iron which we have found representative of hard, medium and soft cast iron as ordinarily found in the average machine shop in this country. In each shop, however, accurate experiments should be made to determine the average cutting speeds of the cast iron actually used. It should be noted also that the cutting speeds given in these tables are those which should be used in order to have the cutting tool last about the length of time stated in Folder 15, Table 108, which we recommend as the most economical time for allowing a tool to run without regrinding.

752 It is of course evident that where slide rules are used in a shop far more accurate results and a larger output can be obtained than with the use of tables similar to those illustrated. However, these tables may be of some interest and we hope also of practical use.

753 This section of the paper is entitled "The Effect of Varying the Feed and the Depth of the Cut upon the Cutting Speed." It should be noted that a change in feed produces a change in the thickness of the chip which is cut by the tool, and that it is the actual thickness of the chip as it crosses the line of the cutting edge of the tool which causes or produces the change in cutting speed. The thinner the chip or shaving the higher the cutting speed, and the thicker the chip the slower the cutting speed. (See paragraphs 292 to 297, explaining the causes for wear on tools and the effect of the pressure of the chip upon the tool.)

754 Now the actual thickness of the chip is dependent not only upon the coarseness of the feed, that is, the advance of the tool for each revolution of the work, but also:

a upon the shape of the cutting edge of the tool, and

b upon the position of the tool in the tool post; *i. e.*, the angle at which the cutting edge of the tool is set with relation to the center line of the work.

758 In paragraphs 307 to 311 we have pointed out, and in Folder 16, Fig. 112, we illustrate, the fact that with all curved line cutting edges the chip must necessarily vary in thickness at all points, and that a straight line is the only shape for the cutting edge of a tool in which the thickness of the shaving is uniform throughout its width.

759 The experiments on the effect of feed and depth of cut which are of the greatest practical interest, and the results of which are required for everyday use refer to our standard round nosed tools; but, as just explained, with our standard round nosed tools the actual thickness of the shaving is affected by a change in the depth of the cut as well as by a change in the feed, therefore any investigation

made with these standard tools must necessarily include at the same time both the effect of a change in the feed and in the depth of cut upon the cutting speed.

760 With but little thought, therefore, it becomes evident that for the primary or more fundamental investigation as to the effect which the thickness of the chip or shaving has upon the cutting speed, it is desirable to experiment first upon shavings which are uniform in thickness throughout their whole width, and therefore we first describe our experiments with different thicknesses of shaving uniform throughout their width.

EXPERIMENTS SHOWING EFFECT UPON CUTTING SPEED OF VARYING THE THICKNESS OF THE SHAVING, A TOOL WITH STRAIGHT EDGE BEING USED, REMOVING A SHAVING IN ALL CASES EXACTLY ONE INCH WIDE

761 In the early part of this paper it was found necessary to describe (paragraphs 292 to 297) our experiments with tools having a straight cutting edge and a uniform thickness of shaving throughout the length of the cutting edge. In order to avoid repetition, therefore, the reader is requested to read these paragraphs. However, the description there given of the experiments is not complete, and we supplement it here as follows:

762 The cutting speeds obtained in these experiments are laid out on two different types of diagrams. In Folder 16, Fig. 114, they are shown upon ordinary cross-section paper and in Folder 16, Fig. 115, upon logarithmic paper; and a comparison of the two sets of diagrams indicates clearly the great advantage of the logarithmic lay-out over that on ordinary cross-section paper; since, as will be noted, the spots or points indicating the cutting speeds upon the logarithmic paper lie almost in straight lines, and this fact helps greatly in finding the empirical formulæ representing the curves. It will be noted also that all the formulæ representing the laws as investigated by us are of the same general type. With this type of formula it is possible to express a great variety of laws, and, as will be explained in paragraph 1195, this type of formula was adopted because it was capable of being expressed entirely in logarithmic terms, and for this reason all of our laws can be incorporated in a slide rule. However, in most cases in describing the curves which represent the laws deduced we give both the logarithmic and the cross-section lay-out.

763 In studying these diagrams it will be remembered, as before indicated, that each of the figures given in our summary table and each of the spots or points given on the diagram is the result of many

experiments made with carefully standardized tools upon metal as uniform in quality as we were able to obtain.

764 As we have before explained, paragraph 28, owing to the enormous number of experiments made (between 30,000 and 50,000) it would be ridiculous for us to burden any published paper with even the principal details of our experiments. Therefore, it has become necessary for us to show by the sample sheets as indicated in the daily record sheet, Folder 11, Fig. 77, and the general summary sheets, Folder 8, Fig. 45, and Folder 11, Figs. 75, 76, the manner in which we originally recorded the results of our experiments and afterward collected them in groups, and finally drew our conclusions as to the results of each group of experiments. The points or spots, however, which are indicated upon our diagrams and which are given in our tables are in most cases arrived at by carefully plotting the final summary of several sets of similar experiments upon the same sheet of logarithmic paper; and as these experiments were made at different times and upon different pieces of test metal and with different tools, the general conclusions arrived at by us from considering together several sets of experiments instead of any one single set, in our judgment, have enabled us to approximate closely to the true laws governing this art.

EXPERIMENTS SHOWING THE EFFECT UPON CUTTING SPEED OF VARYING THE DEPTH OF THE CUT, A TOOL WITH STRAIGHT EDGE BEING USED, REMOVING IN ALL CASES A SHAVING 0.03 INCH THICK

765 Having shown the effect upon the cutting speed of varying the thickness of the shaving it is desirable to show the effect of changing the depth of the cut upon the cutting speed; and this again fundamentally can best be accomplished by a study of tools with straight line cutting edges. For a description of these experiments we again refer our readers to paragraph 299. In further discussion of these experiments we would call attention to the logarithmic and cross-section paper diagrams in Folder 17, Figs. 118, 119, on which these experiments are plotted.

766 The experiments above described with straight edge tools both upon varying the thickness of the chip and varying the depth of the cut were made in 1886 with carbon tools, a heavy stream of water being used to cool the tool. As these experiments were made for the purpose of obtaining certain theoretical information rather than for practical everyday use in making our slide rules, they have not been repeated since that time. It is evident, therefore, that it is of

very great importance to repeat these experiments using the best modern high speed tools and thus bringing this branch of our work up to date. A series of experiments of this sort was planned by us for this summer, but owing to lack of time it has not been carried far enough to record in this paper.

EFFECT OF VARYING THE THICKNESS OF THE FEED AND DEPTH OF CUT UPON THE CUTTING SPEED WHEN OUR STANDARD ROUND NOSED TOOLS ARE USED IN CUTTING STEEL

767 In Part 1 of this paper we have called attention to the fact that the difficulty of obtaining mathematical expressions or formulæ which accurately correspond to the data obtained in our experiments has been almost as great as that of making the experiments themselves, and we may say that through a very considerable portion of the past 26 years we have worked at the mathematical side of this problem. The writer believes that he is well within the limit in stating that during this time we have tried and developed hundreds of formulæ in our endeavor to give accurate mathematical expression to the facts. It may, therefore, be a matter of interest to briefly indicate the logic back of the type of formula finally adopted.

768 It will be noted by referring to Folder 5, Figs. 21a, 21b, that all of our standard tools are similar in their general outline. They consist of an arc of a circle, whose radius is r, at their extreme noses, supplemented by another arc of a circle giving the remainder of the cutting edge of the tool; and in the general similarity existing between these tools it will be observed that the radius of the curve at the extreme nose of the tool may he said to be the controlling factor or element.

769 We have several times pointed out the fact that a curved cutting edge in a tool cuts a shaving varying in its thickness at all points, and it is evident that the rate at which this shaving grows thicker as the cutting edge recedes from the extreme point of the nose bears a certain relation to the radius r, above referred to. This will be seen by referring to the enlarged curves of our standard tools on Folder 17, Fig. 120. Generally speaking, the shaving grows thicker more rapidly the smaller the radius r of the curve, and since the thicker the shaving, the slower becomes the cutting speed, there is thus seen a general relation between this radius r and the cutting speed.

770 This relation is expressed in the following general formula in which

V = standard cutting speed in feet per minute. (For definition of standard cutting speed, see paragraph 140)

F = thickness of the feed in inches, *i. e.*, advance of the tool in inches for each revolution of the forging;

D = depth of cut in inches, *i. e.*, half of the amount by which the forging is reduced in diameter by the cut;

r = radius of nose of tool = one-half width of shank of tool in inches — $\frac{5}{32}$ inch, shown on Folder 5, Fig. 21a,

and in which the value of the constant depends both upon the hardness of the material to be cut and on the quality of the tool, in such a manner that the harder the material, the smaller this constant, and the better the tool the greater this constant:

$$V = \frac{\text{Constant}\left(1-\frac{8}{7(32r)^2}\right)^*}{F^{\frac{2}{3}} + 5 + \frac{2.12}{32r}\left(\frac{48}{32r}D\right)^{1.5} + 0.06\sqrt{32r + \frac{0.8\,(32r)}{6\,(32r)+48D}}} \qquad [A]$$

771 The reasons for the particular form of this general formula are so many and complexly interwoven that it would require pages of description to set them forth; and inasmuch as the whole formula is empirical our reasons are after all of minor interest.

772 We would, however, call special attention to the fact that the particular formulæ developed from our general formula fit in quite a remarkable way the actual data obtained in our experiments. This will be noted by examining the curves of the diagrams representing each formula in their relation to the spots or points on these diagrams representing the facts. Moreover, inasmuch as these experiments were made by different experimenters and at different times and upon different pieces of metal with different sets of tools, it adds very greatly to the probability of the general accuracy of our work that it has been possible to find a single general formula which fits so closely to all these practical results. It is perhaps, on the whole, the best possible evidence that the experiments have been accurately and conscientiously made, and proves beyond a doubt that general laws exist covering this whole field.

773 For the various tools up to and including $1\frac{1}{4}$" to which we can apply this formula with reasonable accuracy, formula [A], paragraph 770, becomes:

*The expression $\left(1-\frac{8}{7(32r)^2}\right)$ in the numerator of the general formula [A] was arrived at by a comparison of the cutting speeds obtained by standardizing various sized tools on the same forging preparatory to using them in any one of the separate series of experiments subsequently made.

774 For $\frac{1}{2}''$ tool, for which $r = \frac{3}{32}''$,

$$V = \frac{\text{Constant} \times 0.873}{F^{0.665}\left(\frac{48}{3}D\right)^{0.2373 + \frac{2.4}{18+48D}}} \qquad [B]$$

775 For $\frac{5}{8}''$ tool, for which $r = \frac{5}{32}''$,

$$V = \frac{\text{Constant} \times 0.954}{F^{0.612}\left(\frac{48}{5}D\right)^{0.2675 + \frac{4}{30+48D}}} \qquad [C]$$

776 For $\frac{7}{8}''$ tool, for which $r = \frac{7}{32}''$,

$$V = \frac{\text{Constant} \times 0.977}{F^{0.5767}\left(\frac{48}{7}D\right)^{0.2921 + \frac{5.6}{42+48D}}} \qquad [D]$$

777 For $\frac{9}{8}''$ tool, for which $r = \frac{9}{32}''$,

$$V = \frac{\text{Constant} \times 0.986}{F^{0.5514}\left(\frac{48}{9}D\right)^{0.3133 + \frac{7.2}{54+48D}}} \qquad [E]$$

778 For $1''$ tool, for which $r = \frac{11}{32}''$,

$$V = \frac{\text{Constant} \times 0.991}{F^{0.5325}\left(\frac{48}{11}D\right)^{0.3323 + \frac{8.8}{66+48D}}} \qquad [F]$$

779 For $1\frac{1}{4}''$ tool, for which $r = \frac{15}{32}''$,

$$V = \frac{\text{Constant} \times 0.995}{F^{0.506}\left(\frac{48}{15}D\right)^{0.3657 + \frac{12}{90+48D}}} \qquad [G]$$

781 We will now proceed to describe some of the more prominent sets of experiments made by us with various sized tools, and which form the basis for the above given formulæ.

782 EXPERIMENTS WITH $\frac{7}{8}$ INCH STANDARD ROUND NOSED TOOL. (Shown in Folder 8, Fig. 45). On Folder 18, Table 129, will be found a sample summary sheet of one of our series of experiments made with our standard $\frac{7}{8}$ inch tool. In this table are recorded the important data connected with each experiment made with each individual tool. In this series of experiments we were, on the whole, successful in having a combination of uniform quality of metal to cut, unusual uniformity in the cutting tools, and also great care on the part of the experimenter; and it is seldom that all of these favorable conditions

are found in any one set of experiments. This table may, therefore, be said to represent one of the best series of experiments made by us.

783 The conclusions noted in this table will be found in the summary table, Folder 18, Table 129, and alongside of them are entered also the cutting speeds as figured by the formula given below. A comparison of the cutting speeds given by the formula in paragraph 777 with the proper constant covering this series of experiments as given in formula, paragraph 783, and those actually obtained in experiments will illustrate the degree of accuracy attained both in the experimental and mathematical work. Our conclusions are again plotted as points or spots upon ordinary cross-section paper in the diagram, Folder 18, Fig. 127, and again in a logarithmic lay-out in Folder 18, Fig. 128.

$$V = \frac{13.4}{F^{0.5514}\left(\frac{48}{9}D\right)^{0.3133 + \frac{7.2}{54 + 48D}}} \qquad [H]$$

784 The constant to be substituted in this formula for the best speed tool, No. 1 (on medium steel), as explained in paragraph 786, is 21.46.

785 The curves plotted in Folder 18, Fig. 127, and in Folder 18, Fig. 128, are a graphical expression of this formula. This set of experiments was made with tools of the chemical composition given in the printed matter beneath the diagrams. Further details regarding this tool and its cutting speed with relation to other high speed tools will be found in Folder 21, Table 139, opposite tool No. 27. The chemical composition and the physical properties of the metal experimented upon will also be found in the printing beneath the table and diagrams.

786 It will be noted that tools differing in their chemical composition were used for making the several sets of experiments described by us. In order to render the formula useful for the best modern high speed tools we therefore give, close to each formula, a constant which should be substituted in the formula if the best modern high speed tool had been used in making the particular experiment (we here refer to tool No. 1, Folder 20, Table 138); and also if the steel cut by this tool had been the medium steel referred to in Folder 20, Table 138, of the following chemical and physical properties:

Carbon	0.34
Manganese	0.54
Silicon	1.76
Phosphorus	0.037

Sulphur	0.026
Tensile Strength	70280 lbs.
Elastic Limit	34630 lbs.
Percentage of stretch	29
Percentage of contraction	44.34

EXPERIMENTS WITH STANDARD 1 INCH TOOL (SHOWN IN FOLDER 5, FIG. 25a)

787 On Folder 18, Table 126, are recorded the results of experiments similar to those described in paragraphs 782 to 785, with $\frac{7}{8}$ inch tools, and in Folder 18, Fig. 125, is given the logarithmic lay-out of the results of this experiment. Formula, paragraph 787, below, which is the same as formula paragraph 778, with the proper constant, gives a mathematical expression corresponding to the results of this experiment. (For definition of the values given in this formula, see paragraph 770)

$$V = \frac{14.7}{F^{0.5323}\left(\frac{48}{11}D\right)^{0.3323 + \frac{8.8}{66 + 48D}}} \qquad [J]$$

788 The constant to be substituted in this formula for the best high speed tool No. 1, as explained in paragraph 786, is 21.56.

EXPERIMENT WITH STANDARD $\frac{1}{2}$ INCH TOOL, AS SHOWN IN FOLDER 5, FIG. 25d and 21a.

789 In Table 131, Folder 18, are recorded the results of experiments similar to those described in paragraphs 782 to 785 with $\frac{7}{8}$ inch tools, and in Folder 18, Fig. 130, is given the logarithmic lay-out of the results of these experiments. Formula, paragraph 789, below, which is the same as formula paragraph 774, with the proper constant, gives a mathematical expression corresponding to the results of these experiments. (For definition of the values given in this formula, see paragraph 770)

$$V = \frac{11.9}{F^{0.665}\left(\frac{48}{3}D\right)^{0.2373 + \frac{2.4}{18 + 48D}}} \qquad [K]$$

790 The constant to be substituted in this formula for the best high speed tool, No. 1, as explained in paragraph 786, is 19.

791 Similar experiments were made with our standard $\frac{3}{8}$ and $\frac{3}{4}$

inch tools, covering, however, not so wide a range of feeds and dep of cut, and the following formulæ represent with fair accuracy th tools when using the best high speed tool, No. 1, on medium st as explained in paragraph 786.

792 For $\frac{5}{8}$ inch standard tool, as shown in Folder 5, Fig. 2 use formula (C), paragraph 775, except that the following will substituted for the numerator:

20.77

793 For $\frac{3}{4}$ inch standard tool, as shown in Folder 5, Fig. 2 use formula (D), paragraph 776, except that the following will substituted for the numerator:

21.26

794 For $1\frac{1}{4}$ inch standard tool, as shown in Folder 5, Fig. 2 use formula (G), paragraph 779, except that the following will substituted for the numerator:

21.66

THE EFFECT OF VARYING THE THICKNESS OF FEED AND DEPTH OF C UPON CUTTING SPEED WHEN OUR STANDARD ROUND NOSED TOOLS ARE USED IN CUTTING CAST IRON

795 As heretofore explained, the difficulty in making a compl and consistent series of experiments upon cast iron is very gr owing to the fact that masses of cast iron of uniform hardness and s ficiently large to make the many tool runs required can but rarely made. After many trials we finally obtained three test pieces of c iron, cast with a hollow core so as to give a comparatively thin secti the metal of which was proved in our experiments to be remarka uniform.

796 These test pieces, however, contained only enough me to make thorough experiments with a single sized tool.

797 As the law for cutting cast iron is only slightly differ in character from that for cutting steel, we therefore assume tha similar relation exists between different sized tools in cutting c iron and in cutting steel. The following formulæ are based up this assumption and apply to tool No. 1 on medium cast iron.

798 For $\frac{1}{2}$ inch tool

$$V = \frac{68.3}{(20F)^{0.6383 - \frac{0.3}{1 + 10F}} \left(\frac{32}{3}D\right)^{0.1743 + \frac{0.27}{3+32D}}}$$

799 For $\frac{5}{8}$ inch tool

$$V = \frac{65.4}{(20F)^{0.5853 - \frac{0.3}{1+100F}} \left(\frac{32}{5}D\right)^{0.2182 + \frac{0.27}{3+32D}}}$$

800 For $\frac{7}{8}$ inch tool

$$V = \frac{62.0}{(20F)^{0.55 - \frac{0.3}{1+100F}} \left(\frac{32}{7}D\right)^{0.25 + \frac{0.27}{3+32D}}}$$

801 For $\frac{9}{8}$ inch tool

$$V = \frac{59.0}{(20F)^{0.5248 - \frac{0.3}{1+100F}} \left(\frac{32}{9}D\right)^{0.2757 + \frac{0.27}{3+32D}}}$$

802 For 1 inch tool

$$V = \frac{56.9}{(20F)^{0.5058 - \frac{0.3}{1+100F}} \left(\frac{32}{11}D\right)^{0.2978 + \frac{0.27}{3+32D}}}$$

803 For $1\frac{1}{4}$ inch tool

$$V = \frac{54.1}{(20F)^{0.4793 - \frac{0.3}{1+100F}} \left(\frac{32}{15}D\right)^{0.335 + \frac{0.27}{3+32D}}}$$

EXPERIMENT WITH A $\frac{3}{4}$ INCH STANDARD ROUND NOSED TOOL
(AS SHOWN ON FOLDER 5, FIGS. 25b AND 21a)

804 Tools of the following chemical composition were used in this experiment:

Tungsten	14.71	per cent
Chromium	2.90	per cent
Carbon	0.70	per cent
Manganese	0.12	per cent
Silicon	0.196	per cent
Phosphorus	0.017	per cent
Sulphur	0.010	per cent

Their cutting speeds with relation to other high speed tools will be found by referring to tool No. 20, on Folder 20, Table 138.

805 On Folder 11, Table 76, we give the detail tool runs of one of our best sets of experiments made in cutting rather hard cast iron. The details of these experiments are given in order that a fair estimate may be formed as to the accuracy of the work. On Folder 19, Table 136, column 1, is given a summary of the results obtained in this series of experiments, and in adjoining columns will be found the corresponding figures as represented by the formula which we have developed and which expresses what we believe to be laws governing the effect of feed and depth of cut upon cutting speed in cutting this quality of cast iron.

806 On Folder 19, Fig. 134, are given two logarithmic plots of the same experiments. In one of these plots the feeds are given at the bottom and the depth of cut at the side, while in the other the depths of cut are given at the bottom and the feeds at the side. A study of these two diagrams side by side will indicate the effect both of varying the thickness of shaving and the depth of the cut, considered one with relation to the other.

807 On Folder 19, Fig. 135, we also show the same experiments plotted on ordinary cross-section paper. This again furnishes an illustration of the greater simplicity and adaptability of the logarithmic lay-out and particularly its advantage in developing formulæ which shall express the laws.

808 Unfortunately, the silicon was the only element accurately determined for the various bars of cast iron experimented upon by us at this time. The silicon of the bar in question was 1.10 per cent. The lines drawn upon the various diagrams just referred to represent the following formula:

$$V = \frac{54}{(20F)^{0.55-\frac{0.}{1+100F}}\left(\frac{32}{7}D\right)^{0.25+\frac{0.27}{3+32D}}} \qquad [L]$$

809 It will be noted that the experiments above described upon the cast iron test piece containing 1.10 per cent of silicon include the following feeds:

0.0156″ 0.0316″ 0.0632″ 0.0127″

and the following depths of cut:

$\frac{3''}{32}$ $\frac{3''}{16}$ $\frac{3''}{8}$

This casting did not contain a sufficient quantity of metal to make tests with the combinations of depth of cut and feed which are needed

to more fully establish the law sought for. Therefore, two additional castings were made and experimented upon. It was our aim to have the same quality of cast iron in these castings as in the one containing 1.10 per cent of silicon. In this, however, we were not successful, as both of the other castings were considerably softer. One of these supplementary castings contained 1.12 per cent silicon, while the other contained 1.20 per cent silicon, and they varied considerably in hardness, as will be seen from their constants in the formulæ. On the test casting containing 1.12 per cent of silicon, experiments were made with cuts $\frac{5}{8}$ of an inch in depth and using feeds from 0.0156 to 0.0632 inch; and a sufficient number of experiments were made also with a depth of cut of $\frac{3}{16}$ of an inch to properly tie together these experiments and the former experiments made on the test piece containing 1.10 per cent of silicon; *i. e.*, to accurately determine the relative hardness of the two castings.

810 On Folder 19, Table 136, column 2, is given a summary of the the results obtained in this experiment and also alongside, the results as figured by the same formula, paragraph 808, for the experiments on the 1.10 per cent silicon bar, except that the constant instead of being 54 for this quality of cast iron is 66.7.

811 On Folder 19, Fig. 132, is also given a logarithmic lay-out of these experiments.

812 A third series of experiments was made upon the cast iron test piece containing 1.20 per cent of silicon. In this case most of the experiments were made with a $\frac{5}{8}$ inch depth of cut. However, a $\frac{3}{16}$ inch depth of cut was also used for tying these various sets of experiments together. A summary of the results of these experiments will be found on Folder 19, Table 136, column 3, with the results as figured by the formula in adjacent columns. The same formula (paragraph 808) was used for this set of experiments as for the experiments with a 1.10 per cent silicon test bar except that the constant in this case was 70.9 instead of 54, showing that this test piece was materially softer than the other.

813 By comparing the lines which represent each formula upon the three diagrams with the points or spots which indicate the actual cutting speeds obtained, it will be noted that, on the whole, the same formula fits very closely to the three sets of experiments, and attention is again called to the fact that while these experiments were made at different times and with different sets of tools, yet after several years we have been able to find a single mathematical expression which represents with a very considerable degree of accuracy the results obtained in all of these experiments.

814 This fact, in our judgment, adds very greatly to the value of the work, because if the experimental results had been such that no mathematical expression could be found which fitted them with accuracy, either one of two conclusions must be drawn: namely, that the conditions under which the experiments were made were such that accurate results could not be obtained, or else that the nature of the work in this whole field of experiments was such as to make it impossible to obtain truly scientific results. It is, therefore, a matter of the greatest gratification to us that it has been possible to represent these various experiments by exactly the same formula, excepting that the constants 54, 66.7 and 70.9 were required to represent the three different grades of hardness in the three qualities of cast iron.

THE INFLUENCE WHICH THE QUALITY OF METAL BEING CUT HAS UPON THE EFFECT OF VARYING THE FEED AND DEPTH OF CUT ON THE CUTTING SPEED

815 With high speed tools as originally developed by us the quality of the metal being cut had a very marked influence upon the laws governing the effect of varying the feed and the depth of cut upon the cutting speed. The following is an illustration of this effect.

816 With high speed steel of the chemical composition indicated for tools Nos. 26 and 27 (the original high speed tools developed by Messrs. Taylor and White), the quality of the tool steel was such that in cutting medium and hard steels, there was practically no increase in the cutting speed of the tool when feeds were used which were finer than $\frac{1}{16}$ of an inch; in other words, a feed of $\frac{1}{64}$ inch, $\frac{1}{32}$ inch and $\frac{1}{16}$ inch all had about the same cutting speed.

817 On the other hand, with tools of this quality in cutting a very soft forging, there was about the same proportionate gain in cutting speed on a cut taken with a $\frac{1}{32}$ inch feed over a cut taken with a $\frac{1}{16}$ inch feed, as there was with a cut taken with a $\frac{1}{16}$ inch feed over that taken with a $\frac{1}{8}$ inch feed.

818 As an illustration of this fact, we give below three cutting speeds, which were taken on a soft forging of the following chemical composition and physical properties:

Tensile strength	56,250 lbs.
Elastic limit	26,590 lbs.
Percentage of stretch	35.50
Percentage of contraction	56.26
Carbon	0.22 per cent
Manganese	0.42 per cent

Silicon .....0.07 per cent
Phosphorus.....0.022 per cent
Sulphur .....0.025 per cent

819 These experiments, which were very carefully made with standardized $\frac{7}{8}$ inch high speed tools (of the chemical composition, shown for tool No. 27, Folder 21, Table 129) on a forging of uniform metal gave the following cutting speeds:

For $\frac{3}{16}$ inch depth x $\frac{1}{16}$ inch feed .....120 ft. per minute
For $\frac{3}{16}$ inch depth x $\frac{1}{32}$ inch feed .....180 ft. per minute
For $\frac{3}{16}$ inch depth x $\frac{1}{64}$ inch feed .....260 ft. per minute

820 Thus it is seen that as the shaving or chip grows thinner, the cutting speed grows more rapid even in taking very fine feeds, whereas, as just explained above, with these same tools in cutting the medium or harder metals, no gain in cutting speed resulted from finer feeds than $\frac{1}{16}$ of an inch.

821 One of the great improvements of the latest high speed tools over the original high speed tools lies in the fact that a tool, for instance, of the chemical composition of tool No. 1, Folder 20, Table 138 (the best modern high speed tool), makes approximately the same gain in cutting speed when using very fine feeds in cutting even very hard steel as the original tools made only when cutting the very softest of steels. And this again is of truly great importance to the average machine shop, since in the average shop more cuts are taken with feeds finer than $\frac{1}{16}$ inch than with coarser feeds, and therefore a proportionate increase in cutting speed is made possible by the latest tool steels over fully one-half of the work in which no such gain was possible with the original tools.

822 As an illustration of this fact, we give the following experiments made by us during the summer and fall of 1906 with modern high speed tools in cutting very hard metals with fine feeds. The following are the details of one of these experiments made with composition of tool No. 2 on Folder 20, Table 138, in cutting the hard steel bar referred to in the same table having the following chemical composition and physical properties, our standard $\frac{7}{8}$ inch round nosed tool (see Folder 5, Fig. 24) being used in these experiments.

Tensile strength ..... { 91670 / 101860
Elastic limit ..... { 60090 / 53980
Percentage of stretch ..... { 7 / 5

Percentage of contraction	11.66 9.73
Carbon	1.00 per cent
Manganese	1.11 per cent
Silicon	0.305 per cent
Phosphorus	0.036 per cent
Sulphur	0.049 per cent

823 The following cutting speeds were obtained with our standard $\frac{7}{8}$ inch tool with a standard 20-minute cut:

a for $\frac{3}{16}$ inch depth x $\frac{1}{16}$ inch feed, cutting speed 41.4 ft. per minute.

b for $\frac{3}{16}$ inch depth x $\frac{1}{32}$ inch feed, cutting speed 58.2 ft. per minute.

c for $\frac{3}{16}$ inch depth x $\frac{1}{64}$ inch feed cutting speed 81.4 ft. per minute.

827 A comparison of the gain in cutting speed when taking fine feeds on this very hard forging will show that they are not far from proportional to the gain made in taking the fine feeds on very soft metal with the original high speed tools as given in paragraph 819.

828 In paragraphs 1058 and 1063 we point out the fact that the reason why the latest high speed tools are able to make the same proportionate gain with fine feeds in cutting hard metals as when cutting soft metals is due to their possessing in a marked degree the two qualities of "red hardness" and "hardness." The original tools as developed by us were deficient as compared with the modern tools in the proper combination of red hardness and hardness.

829 We have made many experiments with tools larger than our standard $1\frac{1}{4}$ inch tool referred to in this paper, one of the most notable of these being a set with tools 2 inches square in the body having their cutting edges corresponding to our $1\frac{7}{8}$ inch standard. It has been impossible as yet, however, for us to obtain sufficiently conclusive results to enable us to state definitely the cutting speeds of these larger types of tool when taking greater depths of cut and coarser feeds than those already experimented with.

830 Accurate experiments of this nature are greatly needed to establish the proper cutting speeds for the few machine shops in which these very heavy cuts are taken. The expense of such experiments, however, is very great, and we have not yet had the opportunity of carrying them to their proper end. The formula which we give on this subject is, therefore, of very questionable value. We may state, however, that with our standard $1\frac{7}{8}$ inch round nosed tool with a cutting edge of the shape indicated in Folder

5, Fig. 21a, as high cutting speeds can be taken in all cases as those indicated in the small summary table, Folder 23, Table 142, when using the best modern high speed steel similar to that of No. 1 tool, Folder 20, Table 138.

831 It will be noted that we have in all cases stated the chemical composition of the tools with which from time to time our experiments as recorded have been made. We also give some of the details of experiments made with the best modern high speed tools for the purpose of accurately comparing the various cutting properties of these tools with the cutting properties of various types of tools formerly experimented with by us. As a result of these experiments we have been able to state what we believe to be approximately the proper cutting speeds for high speed tools under various conditions.

832 It must be remembered, however, that our comparatively few experiments with these tools did not cover the whole field. We attempted to make what we believed to be typical experiments, but we did not feel satisfied with either the extent or the thoroughness of this work. Therefore, it seems of great importance to more carefully verify the various laws obtained by us through direct experiments with the latest high speed tools. Among these for the purpose of establishing the fundamental basis upon which rests the effect of varying the feed and the depth of cut upon cutting speed, we think it of particular importance to make a series of experiments with tools having straight line cutting edges, both on the effect of the thickness of the chip upon the cutting speed and upon the effect of the depth of the cut upon the cutting speed. Such experiments should be similar to those made by us upon this subject with carbon tools, as described in paragraphs 292 to 299.

833 Attention is called to the necessity of determining accurately the effect of the thickness of the chip or a change in the feed, and also the effect of the depth of the cut upon the cutting speed when a heavy stream of water is used to cool the latest modern high speed tool.

TOOL STEEL AND ITS TREATMENT

CHEMICAL COMPOSITION AND HEAT TREATMENT OF TOOL STEELS

934 Among modern experiments upon the chemical composition and the heat treatment of tools with relation to their cutting speeds, the experiments made by the firm of Armstrong, Whitworth & Company, the celebrated ship, cannon and machine builders of England, would seem to rank in thoroughness next to those made by Mr. White and

the writer at the Bethlehem Steel Works. Or it would be more correct to say that no other published experiments have come to the writer's attention which appear to him to have been so carefully conducted.

935 In a paper entitled "The Development and Use of High-Speed Tool Steel" (published in the Journal of the Iron and Steel Institute, October, 1904), Mr. J. M. Gledhill, Managing Director of Armstrong, Whitworth & Company, has given a brief account of these experiments. The opening paragraphs of this paper present such a concise and interesting historical sketch of the development of tool steel and its treatment that the writer takes the liberty of quoting them as follows:

936 "It would doubtless have been felt by many but a few years back that there was little left to be said on the subject of crucible tool steel, and that something akin to finality had been arrived at in its manufacture and general treatment. Probably such feeling was justifiable when it is remembered that the making of steel in crucibles is by far the oldest method known, dating back from time immemorial, it being indeed impossible to accurately trace its origin and earliest development, but it seems certain that carbon steel was made and used thousands of years ago for cutting tools. Proof of this may be seen by the marvellous carvings and workings on the intensely hard stone work of the ancients, for it would be difficult to conceive by what means, other than with steel tools, such work could have been executed, and it is wonderful to contemplate that steel-cutting tools should have been used so long ago, whilst the principle of manufacturing them—that is, by fusion of iron and charcoal in crucibles—was then in a measure on the same lines as we work on at the present day. Archæologists have discovered that the Chinese made steel in crucibles long before the Christian era.

937 "Wootz" steel fabricated in India centuries ago was crucible steel, as was also the celebrated Damascus steel, produced at the forges of Toledo. Curiously, this latter steel furnishes yet another proof that there is nothing new under the sun, for it is recorded that Damascus steel contained certain percentages of tungsten, nickel, manganese, etc., some of the very elements, in fact, contained in the present modern high speed steel, so that a latent high speed steel may be said to have existed centuries ago, and all that was necessary to bring out its inherent powers would have been the heating of it in a paradoxical manner, so to speak; that is, to such a high degree of temperature as was long thought would impair or destroy the nature of such steel. When, therefore, we look back on the period for which

crucible steel has been known in the world's history, some may not unnaturally think that there has been time enough to have fully fathomed its mysteries leaving little more to be said on the subject. It is then all the more remarkable that a discovery, made but a few years back, and which has since revolutionized the treatment of crucible tool steel, should have remained so long a hidden secret.

938 "A very important advance was made thirty or forty years ago, when 'Mushet,' or self-hardening steel, was introduced. This was the valuable invention of Robert Mushet, who, after a long series of experiments, made whilst he was manager of the Titanic Steel Company; succeeded in producing a tungsten steel, and its introduction was a great advancement on the cutting powers of ordinary crucible steel, and for many years 'Mushet' steel held a foremost place amongst tool steels.

939 "It is now to America, however, that all honor must be given for the next great step in having 'set the pace' and led the way in the present remarkable advancement in tool steel, and the author would here like to record that the greatest credit is due to Messrs. Taylor and White, who at the Bethlehem Steel Works of America, initiated high-speed cutting, and at the exhibit of their firm in Paris some years back, what were then considered to be astonishing results in speeds of cutting steel were publicly demonstrated. Since then, still greater developments have been made by the author's firm in high-speed steels, and with increased experience in its manufacture, treatment, and application in our workshops, results in cutting powers far beyond expectation have been attained."

ORDINARY TOOL STEEL

940 For centuries steel weapons, knives, tools and implements used in cutting metals have been made from tool steel which in its chemical composition consists mainly of the two elements of iron and carbon--carbon to the extent of say from $\frac{3}{4}$ of 1 per cent to $1\frac{1}{2}$ per cent--and the rest of the steel consists practically of iron. In addition to these two elements, however, tool steel has contained in small quantities several other ingredients, among which manganese and silicon may be classified as useful elements; *i. e.*, elements which facilitate melting and forging, and which by their presence improve the properties of the steel in its finished state. In addition to these elements very small percentages of phosphorus, and sulphur, are always present. These latter may be described or classified as impurities. Phosphorus is particularly injurious, as it causes brittleness in the finished steel known as "cold shortness." Sulphur renders the steel

difficult to work while hot, and this is known as "red shortness." This tool steel which has been in use for centuries past, and which, broadly speaking, consists mainly of a combination of carbon and iron, is now known as "carbon tool steel" or "ordinary tool steel".

HARDENING

941 Tools and implements made from this steel, however, are entirely too soft as they come from the forge for almost all cutting purposes. In order to prepare them for cutting, they must be hardened, and this is done by heating them to temperatures in accordance with their carbon contents, varying between a dark and a bright cherry red, say, from 1350 degrees Fahr. (735 degrees Cent.) up to 1550 degrees Fahr. (845 degrees Cent.), and then by plunging them quickly into water or other suitable bath, cooling them very rapidly to a temperature not exceeding 392 degrees Fahr. (200 degrees Cent.), or preferably to the normal temperature of the air. This operation is called "hardening."

TEMPERING

942 When cooled suddenly in this way, implements and tools made from carbon tool steel are too brittle for most cutting purposes. This quality of brittleness is removed or modified by reheating to temperatures ranging between 392 degrees Fahr. (200 degrees Cent.) and 600 degrees Fahr. (315 degrees Cent.). The higher the tool is reheated within these ranges of temperature, the softer it becomes, and this reheating for the purpose of partially softening and at the same time toughening the tool is the operation known as "tempering the tool."

ORDINARY TOOL STEEL

943 The two operations of hardening and tempering implements made from tool steel are by no means simple. They have been the subject of a vast amount of experimenting and investigation for many years and in themselves constitute whole trades.

944 The chief difficulties in hardening come from three causes:

945 (A) Each ordinary tool steel, depending upon its chemical composition, has a particular temperature at which a radical change takes place in the condition of the carbon which is contained in it. This temperature known as the "refining point," "critical point," or "point of recalescence" of the steel, will be briefly referred to later in the paper. In order to obtain the best results in hardening the steel should be uniformly heated to slightly above this critical point.

If heated below the critical point, it fails to harden when plunged into water. On the other hand, the higher the temperature to which it is heated above the critical point, the coarser will be the grain and the weaker and more brittle it will become after being plunged into water. This overheating of carbon steel tools to temperatures too high above the critical point has been in the past perhaps the most frequent cause of their failure. Hence the difficulty in judging the critical point for heating tools presents one of the most serious problems in hardening.

946 (B) The second difficulty lies in not heating the tools uniformly. A lack of uniformity in heating will produce irregularity in the degree to which the tool is hardened, some portions being much harder than others after quenching, and this sets up severe internal strains in the tool, frequently developing into water cracks.

947 (C) The third difficulty lies in properly cooling the tool in the water or quenching medium. Uneven or irregular cooling also produces severe internal strains often resulting in water cracks.

948 The correct tempering of tools presents also many difficulties. In most cases it is desirable to temper tools or implements so that the cutting portion shall remain exceedingly hard while the body is softened, and thereby made sufficiently tough to give it the required strength. This necessary combination of toughness and hardness calls for great skill and judgment in the reheating or softening operation known as "tempering."

949 One of the greatest advantages of modern high-speed tools over the carbon tools lies in the fact that they require far less knowledge and skill in their heat treatment than was demanded by the carbon tools. This will be indicated later in the paper.

MUSHET OR SELF-HARDENING STEEL

950 Some time between 1860 and 1870, Robert Mushet of the Titanic Steel Company in England made the discovery that if a considerable amount of tungsten was added to tool steel in combination with a larger percentage of manganese than had been before used, the presence of these two elements with carbon in the steel produced the curious effect of causing the tool to be almost as hard when cooled only in air from a forging heat as carbon tools when cooled in water. Because of this peculiar property, the Mushet tools were called in England self-hardening tools and later in this country air-hardening tools.

951 The chemical composition of the Mushet tools as analysed for us in the early part of 1905 is given in Table M and paragraph 952.

FOUR EPOCHS IN HISTORY OF STEEL TOOLS. (1) CARBON TOOL STEEL ERA; (2) SELF-HARDENING STEEL ERA; (3) DISCOVERY OF HIGH SPEED TOOLS; (4) MODERN HIGH SPEED TOOLS; WITH ANALYSES OF TOOLS OF THESE ERAS

952 We give below the chemical analyses of four tools which are typical of the various steps or eras in the development of metal cutting tools:

MAKE OF STEEL	TUNGSTEN PER CENT	CHROMIUM PER CENT	CARBON PER CENT	MANGANESE PER CENT	VANADIUM PER CENT	SILICON PER CENT	PHOSPHORUS PER CENT	SULPHUR PER CENT	SPEED PER MINUTE IN FEET CUTTING MEDIUM STEEL
Jessop			1.047	0.189		0.206	0.017	0.017	16
Mushet self-hardening	5.441	0.398	2.150	1.578		1.044			26
Original Taylor-White	8.00	3.80	1.85	0.30		0.15	0.025	0.030	58 to 61
Best modern high speed 1906	18.91	5.47	0.67	0.11	0.29	0.043			99

953 The first of these is the analysis of perhaps the most noted brand of ordinary carbon steel, that made by Messrs. Jessop & Sons of England, which is typical of the era of carbon tools. The second is the analysis of the old fashioned Mushet self-hardening steel as experimented with by us in 1894-95—typical of the era of self-hardening tools. The third is the analysis of the steel recommended by us in our Patent No. 668270 of February 19, 1901, as being, on the whole, the best at the time when modern high speed tools were invented by Mr. White and the writer, marking the beginning of "high speed" or "red hard" tools. The fourth is the analysis of the best high speed tool, so far as we know, which has been developed up to the end of the summer of 1906.

954 For many years the tool steel developed by Mushet was looked upon largely as a curiosity. Gradually, however, the managers of machine shops found that by using tools made from the Mushet steel they were able to cut hard forgings and castings which were difficult to cut with the carbon tools. When this knowledge became quite

general, it was usual for the best machine shops to have a few Mushet tools on hand for cutting specially difficult work, and their use for this purpose grew steadily from year to year.

955 It was not, however, until about 1890 that there was at all a general awakening among managers of machine shops as to the whole question of the cutting speeds of tools, and it may be said that practically up to that time Mushet tools had not been used for the purpose of gaining an increase in cutting speed. In fact, up to the time of our experiments of 1894–95, described in Part I, paragraphs 102, and Part 2, paragraph 956, but few machines, if any, had had their driving speeds increased with a view to profiting by the possible gain in cutting speed obtainable through Mushet or other self-hardening tools.

EXPERIMENTS COMPARING MUSHET AND OTHER SELF-HARDENING AND CARBON TOOLS

956 It was in 1894 that we first had the opportunity to make a careful series of experiments to determine the relative cutting speeds of the Mushet and the carbon tools. We had hitherto been prevented from doing so by the fact that the Midvale Steel Works manufactured and sold tool steel, and up to the time the writer left their employ, they had not gone into the manufacture of self-hardening steel, and therefore would not allow us to make any experiments with it.

957 Our experiments in 1894–95 resulted in the following important discoveries:

958 *a* That, comparing the self-hardening steel with carbon steel, a gain in speed of 41 per cent to 47 per cent could be made in cutting a hard forging of about the quality of tire steel; whereas a gain of nearly 90 per cent could be made in cutting the softer qualities of metal; and

959 *b* that by using a heavy stream of water on the nose of a Mushet or other self-hardening tool, a gain of about 30 per cent could be made in the cutting speed over the speeds possible when the same tools are run without water.

960 These experiments, then, indicated clearly that the use of Mushet steel almost exclusively for cutting exceedingly hard pieces of metal was the wrong one; since an enormously greater percentage of soft metal was cut in the average machine shop than of hard metal, and the gain in cutting soft metals was 90 per cent as against only 45 per cent gain for hard. It thus became evident that instead of using self-hardening tools only occasionally for cutting extra hard pieces of metal, they should be used daily throughout the shop

on all ordinary work in place of the carbon steel tools. From the time on the increase in the use of self-hardening steels was so very great that at the time of our invention of the new high speed tools probably from one-fourth to one-fifth of the roughing tools used in good machine shops had come to be made from self-hardening steel.

961 Between 1885 and 1895 a few manufacturers of tool steel started to imitate the Mushet steel, and in the latter part of this period it was discovered that by substituting chromium for manganese in combination with tungsten a good self-hardening or "air-hardening" tool could be made. After 1890 the competition in the manufacture of self-hardening tool steels grew much more keen; but it is a remarkable fact that the successors to Mushet in the tool steel business, even up to the time of the Taylor-White invention, probably retained one-half of the business in self-hardening tool steel throughout the world. This is an unusual record for any one firm in the manufacture of an standard article.

962 As described in Part 1, paragraphs 102 to 110, at the time that we discovered the beneficial results from heating chromium tungsten tools near to the melting point, tools made by several makers of tool steel, containing largely chromium and tungsten as the self-hardening elements in place of the manganese and tungsten used by Mushet, had equaled in cutting speed the Mushet self-hardening tools.

963 Up to 1894 may be called the era of carbon tools. From 1894 to 1900 when high speed cutting tools, treated by the Taylor-White process, were exhibited at the Paris Exhibition may be called the era of Mushet or self-hardening roughing tools. From 1900 up to the present time may be called the era of high speed tools, and this has become so completely the case that at the present time a carbon or an "untreated"[1] tungsten-manganese or tungsten-chromium roughing tool can scarcely be found in an up-to-date machine shop.

NATURE OF THE INVENTION OF MODERN HIGH SPEED TOOLS

964 In paragraphs 102 and 110 the writer has described the circumstances leading up to the discovery of the facts embodied in the invention of modern high speed tools. There exists in the minds of most users of these tools a serious misapprehension both as to the nature of the invention and also as to that property in high speed

[1]We use the word "treated" as indicating the heat treatment which gives "high speed" tools their new property of "red hardness," namely, heating the close to the melting point, etc., as indicated in paragraphs 979 to 995.

tools which chiefly gives them their value. Perhaps at least four out of five writers upon the subject of high speed tools speak of the "discovery" or "introduction of high speed tool steels," as though our invention consisted in the discovery of a TOOL STEEL new in its chemical composition. The fact is, however, that tool steel of excellent quality for making high speed tools existed and was in common use several years before our discovery was made.

THE QUALITY OF "RED HARDNESS"

965 A second misapprehension exists on the part of most people as to the nature of that property which enables the "high speed" tools to be run at their high speeds. Heating these tools (in a revolutionary manner) up close to their melting point is quite commonly referred to by writers on this subject as "hardening" the tools. In point of fact the high speed tools at their very hardest are little, if any, harder than the carbon tools, or the old fashioned self-hardening tools, and the quality of hardness is not that which enables them to run at very high speed.

966 Heating chromium-tungsten tools close to the melting point does not give them a degree of hardness which is unusual in tools, but it does give them the entirely new and extraordinary property of retaining what hardness they have, even after the tool has been heated up in use through the pressure and friction of the chip, until it is almost, or quite, red hot. This new property in high speed tools has been very appropriately named "RED HARDNESS," because the tool maintains its cutting edge sufficiently sharp and *hard* to cut steel even after its nose is *red hot*, and because in many cases it heats up the chip or shaving which it is cutting until the portions of the chip which are exposed to the friction of the tool become red hot.

967 The fact that hardness of the kind to which we have been accustomed in ordinary tools has but little to do with high speed tools is graphically illustrated on Folder 3, Fig. 18. This is one of the high speed tools of the most approved chemical composition referred to in Folder 21, tool No. 27, and this very tool was run at as high a cutting speed as the high speed cutting tools originally developed by us. After running at its high speed, the two deep indentations or nicks were filed with a file made from ordinary carbon tool steel, one across the cutting edge and the other about ½ inch below the cutting edge, showing that a first-class high speed tool can be readily filed by the old carbon tool steel.

968 As to our invention, briefly speaking, by far the most impor-

tant of the several discoveries made by us, and which led to the modern high speed tools, was the discovery that when tools made from tool steel old in its chemical composition (containing not less than one-half of one per cent of chromium and not less than one per cent of tungsten, or its equivalent) were treated in a new and completely revolutionary manner to an extraordinarily high heat (a heat so high that it would have utterly ruined ordinary tools), this treatment imparted an entirely new quality or property to a cutting tool, namely the property called "red hardness"; and it is this new property which enables these tools to run at their high cutting speeds.

GENERAL COMPARISON OF THE INGREDIENTS OF CARBON TOOLS, SELF-HARDENING TOOLS AND MODERN HIGH SPEED TOOLS

969 Chemically speaking, the era of carbon tool steel may be said to consist of tools containing from $\frac{3}{4}$ per cent to $1\frac{1}{2}$ per cent of carbon in combination with a little manganese and silicon (used to help in melting, casting, and hammering the steel), the rest of the steel being iron.

970 The era of self-hardening tools may be said to consist of about 4 to 11 per cent of tungsten in combination with $1\frac{1}{2}$ per cent to $3\frac{1}{2}$ per cent of manganese with $1\frac{1}{4}$ to $2\frac{1}{4}$ per cent of carbon; and besides these ingredients chromium to the extent of from three-tenths of one per cent to almost 3 per cent was frequently used either as a substitute for the manganese or in addition to it. The rest of the steel consisted of iron with a small amount of silicon used for melting purposes.

971 The era of high speed tool steel may be said to consist of tools containing one-half of one per cent or more of chromium in combination with one per cent or more of tungsten, or its equivalent of molybdenum heated almost to the melting point. The percentages of chromium and tungsten used in high speed tools vary between extremely wide limits. The "one-half per cent or more" of chromium referred to in our patent has been increased in the extreme case to the extent of 7 per cent, and the "one per cent or more" of tungsten has been increased in the extreme case to 26 per cent. The percentage of carbon, on the other hand, has been lowered until the better modern tool steels contain from fifty-five one-hundredths of one per cent to about $1\frac{1}{4}$ per cent as the maximum, and the manganese, silicon and other ingredients have been reduced to quantities sufficient merely for good melting. As above explained, molybdenum has been substituted for the tungsten as an equivalent or mixed with the tung-

dium. Our experiments, however, would indicate that this element is not as desirable as tungsten.

ADDITION OF VANADIUM IN SMALL QUANTITIES IMPROVES QUALITY OF HIGH SPEED TOOLS

972 During the year 1906 our experiments indicate that the addition of a small amount of vanadium, from twenty-five one-hundredths of one per cent to one-half of one per cent, chemically improves the quality of high speed tools, and the best chemical composition which we know of for high speed tools is the following, recently developed by us:

TUNGSTEN	CHROMIUM	CARBON	MANGANESE	VANADIUM	SILICON	PHOSPHORUS	SULPHUR
18.91	5.47	0.67	0.11	0.29	0.043		

GENERAL ON THE TREATMENT OF HIGH SPEED TOOLS NO IMPROVEMENT HAS BEEN MADE IN THE HEAT TREATMENT OF HIGH SPEED TOOLS SINCE THEIR DISCOVERY BY MESSRS. WHITE AND TAYLOR IN 1889-1899

973 Seven years have now gone by since Mr. White and the writer applied for our patents covering the Taylor-White process of making and treating tools, and it is an extraordinary fact that so far as the writer knows, not a single improvement has been made upon the method of heat treatment for producing the high speed lathe and planer and other metal cutting tools described in this patent.

974 During the summer and fall of the present year (1906), we have procured those makes of tool steel which have recently attained the highest reputation for efficiency in England, Germany and America, and have conducted a careful series of experiments with tools shaped and ground exactly alike, in cutting both steel and cast iron of uniform qualities, in order to determine both what chemical composition and what heat treatment would produce a tool of the highest cutting speed.

975 In all cases we obtained detailed instructions from the makers of the steels, telling us just what heat treatment to give tools made from their steels and in some cases men were sent by the manufacturers

to superintend the heat treatment of their tools. In all instances we treated each brand of tool steel exactly as directed and then tested the tools to determine their fastest standard cutting speeds.

976 In addition to this, similar tools (in most cases identically the same tools), made from each make of tool steel were afterward treated in exact accordance with the method indicated in our patent No. 668269 of February 19, 1901, as our preferred method. And without an exception, the same make of tools, when treated in exact accordance with the directions given in our patent, proved more uniform and ran at slightly higher cutting speeds than when treated in accordance with the directions given by the makers.

977 This result is extraordinary, indeed we believe almost unique, in the history of an invention so fundamental and revolutionary in its character. Moreover, the writer must confess to the greatest surprise that although subject to innumerable experiments throughout the entire manufacturing world, the method of treating these tools should not have been radically improved during all these years.

978 For detailed directions as to that heat treatment which will give the very best results in the new high speed tools, therefore, the writer refers all readers to the directions given in the patent above referred to. However, since in past years there has been difficulty at times in obtaining copies of this patent from the Patent Office, we will briefly recapitulate the most important directions for treating modern high speed tools.

FIRST OR HIGH HEAT TREATMENT FOR HIGH SPEED TOOLS. HEATING TOOLS CLOSE TO THE MELTING POINT

979 After the lathe or planer tool has been forged, as described in paragraphs 431 to 471, the entire nose of the tool should be slowly and uniformly preheated to a brigl t cherry red, allowing plenty of time so that the heat may penetrate thoroughly to the center of the tool and thus avoid danger of cracking from too rapid heating. From the bright cherry red up to the melting point, on the other hand, the tool should be heated as rapidly as practicable in an intensely hot fire until the nose begins to soften. In fact, if the extreme exposed portions of the nose are slightly fused no harm will be done. In this operation also thorough and uniform heating is necessary, and time should be given for the whole nose of the tool to arrive at a uniform temperature.

980 No method or apparatus should be used for giving the tools the high heat treatment which heats only a portion of the nose of the

tool. The whole end of the tool from the heel to the lip surface should be uniformly heated to the same high heat.

981 If the fire gives a sufficiently intense heat, a tool of 2 inch by 3 inch body can be thoroughly and properly heated in three minutes from a bright cherry red up to the proper high heat. Without an especially designed furnace, however, it is difficult to obtain a sufficiently uniform and intense heat to treat a tool of this size in three minutes. Smaller tools require from three-fourths of a minute upward, according to the intensity of the fire and the size of the tool, to heat from the cherry red to the high heat.

982 The writer wishes to again emphasize the importance of an intensely hot fire. Various methods for producing this high heat will be referred to in paragraphs 1007 to 1010. If the nose of the tool is exposed to the high heat for too long a time, or if a fire is used which does not give an intensely hot flame, the extreme outside layers of the tool are sometimes slightly injured, probably through oxidization. Therefore, in designing cutting tools, where practicable, they should be forged so as to allow from $\frac{1}{16}$ to $\frac{1}{8}$ of an inch to be ground off at the first grinding. This will insure immediately a tool having the highest cutting speed. It is for this reason that in Folder 5, Figs. 25d to 25e we indicate in dotted lines above and beyond the upper part of the nose of the tool the shape to which the tool should be forged, and in heavy lines the shape to which the tool should be ground at its first grinding. It is of the greatest importance that tools should not be allowed to soak in heating at the high temperatures above a cherry red, as slow heating above this temperature will cause them to be exceedingly brittle, give them a coarse grain and make them likely to firecrack.

COOLING HIGH SPEED TOOLS FROM THE HIGH HEAT

983 In paragraphs 1006 to 1009 we have referred to a certain range of temperatures between 1550 degrees Fahr. to 1700 degrees Fahr., called the breaking down temperatures, and have called attention to the fact that the old fashioned self-hardening tools if heated to within this range of temperatures were seriously injured or broken down in their cutting speeds.

985 To get the best and most uniform results with high speed tools after their high heat has been given them. as above described, they should be cooled rapidly until they are below the breaking down point, or, say, down to or below 1550 degrees Fahr. The quality of the tool will be but little affected whether it is cooled rapidly or slowly from

this point down to the temperature of the air. After all parts of a tool from the outside to the center have reached a uniform temperature below the breaking down point, therefore, it is our practice sometimes to lay it down in any part of the room or shop which is free from moisture, and let it cool in the air, and sometimes to cool it in an air blast to the temperature of the air.

986 We have found the best method of cooling from the high heat to below the breaking down point to be that of plunging them into a bath of red hot molten lead below a temperature of 1550 degrees Fahr. We now plunge them into a lead bath maintained at a uniform temperature of 1150 degrees Fahr., because the same bath is afterward used for reheating the tools to give them their second treatment. This bath should contain a sufficiently large body of the lead so that its temperature can readily be maintained uniform; and for this purpose we use preferably a lead bath containing about 3600 pounds of lead.

987 The largest sized tool when plunged at the high heat into a bath of this size will not materially affect the temperature of the lead. If too small a lead bath is used and one tool after another is plunged into it from the high heat, before, say, the first tool plunged has been cooled uniformly to the temperature of the bath, the lead may possibly be heated to a higher temperature than it had originally, and this rise in the temperature of the lead, if it were to extend beyond 1240 degrees while the tool is in it, would seriously injure the tool.

988 Too much stress cannot be laid upon the importance of never allowing a tool to have its temperature even slightly raised for a very short time during the process of cooling down. The temperature must either remain absolutely stationary or continue to fall after the operation of cooling has once started or the tool will be injured. Any temporary rise of temperature during cooling, however small, will injure the tool. This, however, applies only to cooling the tool to the temperature of about 1240 degrees, Fahr. Between the limits of 1240 degrees and the temperature of the air the tool can be raised or lowered in temperature time after time and for any length of time without injury. And it should also be noted that during the first operation of heating the tool from its cold state to the melting point no injury results from allowing it to cool slightly and then be reheated. It is from reheating during the operation of cooling from the high heat to 1240 degrees Fahr. that the tool is injured.

989 The above described operation is commonly known as the "first" or "high" heat treatment.

To briefly recapitulate, the first or high heat treatment consists in heating the tool:

a slowly to 1500 degrees Fahr.;

b rapidly from that temperature to just below the melting point;

c cooling fast to below the breaking down point, *i. e.*, to 1550 degrees, or preferably to 1150 degrees;

d cooling either fast or slow from this point to the temperature of the air.

THE SECOND OR LOW HEAT TREATMENT

This treatment consists in reheating the tool which has had igh heat treatment to a temperature somewhere between 700 240 degrees Fahr., rather better results being obtained at the r temperatures within these limits.

For this reheating the best practice is to place the tool in a bath containing about 3600 pounds of lead, the temperature of h can be maintained uniform within a few degrees of 1150 degrees with the aid of our exceedingly simple optical pyrometer, and then r cooled in an air blast or laid down to cool in the air. The tool ld be held in this bath about 5 minutes. To avoid danger of fire ks, particularly if the tool is of complicated shape, it should be ed rather slowly before being plunged into the lead.

We have fixed upon 1150 degrees as the temperature of the bath because, even with a sluggish bath slow in either increasing owering its temperature, there is danger through carelessness on part of the operator of allowing its temperature to rise, and so heat- the tool beyond the critical temperature of 1240 degrees. If the l is allowed even for a short space of time to rise in temperature ond 1240 degrees its property of red hardness will be seriously paired, and its cutting speed greatly reduced; and a rise in tempera- e beyond 1350 degrees will completely destroy the property of red rdness in the tool and leave it in its original condition before receiv- the high heat treatment.

To briefly recapitulate, the second or low heat treatment nsists of heating the tool:

a to a temperature below 1240 degrees, preferably to 1150 degrees for a period of about 5 minutes; and

b cooling to the temperature of the air either rapidly or slowly.

The good effects of the second or low heat treatment can be oduced in another way, by running the tool under the friction of the

chip until the temperature of its nose has been raised to within the limits of, say, 700 degrees, to 1240 degrees Fahr. Having been heated under the pressure of the chip in this manner, and then cooled to the temperature of the air, the next time that it is run the tool will have a materially increased degree of red hardness and can be run at a higher cutting speed than it was capable of maintaining after the high heat and before the low heat treatment.

UNIFORMITY THE MOST IMPORTANT QUALITY IN CUTTING TOOLS

993 The writer has many times referred to the necessity of uniformity in the various standards adopted, and in fact we consider uniformity in the red hardness of tools and in their cutting speeds to be the most important element or property sought for.

997 Within one month after having discovered the Taylor-White process we had succeeded in developing a number of tools which were capable of running at as high speeds in cutting steel of medium and soft quality and of lasting as well as any tools developed by us up to the date of application for our patent. The greater part of the time given by us to the development of high speed tools was spent in the effort to obtain uniformity in the tools. The writer looks upon uniformity as of such importance that he does not hesitate to assert that with proper task management more work can be gotten out of a shop with the old fashioned uniform Mushet tools than from a shop without task management and with new high speed tools which are as far from being uniform as they now are in many shops.

998 Under task management it is of great importance that the workman be fully convinced that the man who operates the slide rule and gives him his speed directions is able to tell him with regularity how to remove metal faster than he could remove it without these directions. Without uniform tools, however, the slide rule man will find himself almost as much at sea as the workman, and thus will be completely discredited in the eyes of the latter.

999 It is then for the purpose of obtaining uniformity in the tools that our method and apparatus described above for the high and low heat treatments are particularly desirable. It is a very curious fact connected with the development of high speed tools that there are a great number of ways of giving the high and low heat treatments which will produce first class tools. Perhaps three out of four tools given the high and low heat treatments in these various ways might be called first-class tools. Our method as described above, however, will produce tools which are practically all first-class, and it is for this

reason that we recommend its adoption in all shops in which a sufficient number of tools are treated each day or each week to warrant the expense of maintaining lead baths controlled by accurate pyrometers and a proper furnace for giving the high heat.

1000 It would be manifestly improper for the writer to describe in minute detail the apparatus developed by us for this purpose, because some features of the apparatus were patented, while others were mere questions of proportions and design, and the whole of the patents, apparatus and methods, were sold by us to the Bethlehem Steel Company after making the invention. (See paragraphs 990 and 994)

LITTLE ATTENTION NEED BE PAID TO THE SPECIAL DIRECTIONS GIVEN BY MAKERS OF HIGH SPEED TOOLS FOR THEIR TREATMENT. ALL GOOD HIGH SPEED TOOL STEELS SHOULD BE TREATED IN THE SAME SIMPLE WAY

1001 For some years past it has been rather amusing to us to hear the special directions given by the various manufacturers of steel suitable in chemical composition for making the high speed tools. Very frequently a tool steel maker implies, or directly states that the chemical composition of his particular high speed tool steel requires "special treatment." The fact is, however, as stated above, that our recent experiments demonstrate beyond question the fact, that no other method which has come to our attention produces a tool superior in red hardness (*i. e.*, high speed cutting ability), or equal in uniformity to the method described in paragraphs 979 to 994. This applies to all makes of high speed tool steels which are capable of making first-class tools, whatever their chemical composition.

1002 It is the writer's belief that during our long series of experiments at the Bethlehem Steel Company, in our search for uniform tools and for the method of imparting the highest degree of red hardness to tools, we tried substantially every method which since that time has come to our attention.

1003 For instance, in giving the tools the high heat we heated them in a blacksmith's coke fire, a blacksmith's soft coal fire, in muffles over a blacksmith's fire, and in gas heated muffles. We also constructed various furnaces for this purpose. We heated the tools by means of an electric current, with their noses under water, and out of water, and by immersion in molten cast iron. Moreover, by every one of these methods we were able to produce a first-class tool provided only the tool was heated close to the melting point.

1004 In cooling from the high heat we experimented with a large variety of methods. After being heated close to the melting point,

tools were immediately buried in lime, in powdered charcoal, and in a mixture of lime and powdered charcoal; thus they were cooled extremely slowly, hours being required for them to get below a red heat. And we wish to clearly state the fact that tools cooled even as slowly as this, while they were in many cases quite soft and could be filed readily, nevertheless maintained the property of "red hardness" in as high a degree as the very best tools, and were capable of cutting the medium and softer steels at as high cutting speeds as the best tools which were cooled more rapidly; and which were much harder in the ordinary sense.

1005 Tools were also cooled from the high heat in a muffle or slow cooling furnace with a similar result. On the other hand, we made excellent high speed tools by plunging them directly in cold water from the high heat, and allowing them to become as cold as the water before removing them. Between these two extremes of slow and fast cooling; cooling in lime, charcoal, or a muffle, on the one hand, and in cold water, on the other; other cooling experiments covering a wide range were conducted. We tried cooling them partly in water and then slowly for the rest of the time; partly in oil, and then slowly for the rest of the time; partly by a heavy blast of air from an ordinary blower and the rest of the time slowly; partly under a blast of compressed air and then slowly. We also reversed these operations by cooling first slowly and then fast, as described. We also cooled them entirely in an air blast and entirely in oil, and then partly first in oil, afterward in water, and then first in water and afterward in oil.

1006 By every one of these methods we were able to make a good high speed tool; *i. e.*, a tool having a large degree of red hardness, and capable of cutting at very high cutting speeds. But by none of these processes were we able to obtain tools as uniform and regular as those produced by our lead bath and air cooling.

BEST METHOD OF TREATING TOOLS IN SMALL SHOPS

1007 There are many very small shops in which it is questionable whether the installation of the full apparatus required to treat tools by our preferred method would be warranted. For this class of shops, in treating high speed tools, the writer considers the best method to be as follows, for the blacksmith who is equipped only with the apparatus ordinarily found in a smith-shop:

1008 After the tools have been forged and before starting to give them their high heat, fuel should be added to the smith's fire so as to give a good deep bed either of coke about the size of an English walnut or of first-class blacksmith's soft coal. A number of tools should

then be laid with their noses at a slight distance from the hotter portion of the fire so that they may all be pre-heating while the fire is being blown up to its proper intensity. After reaching its proper intensity, the tools should be heated one at a time over the hottest part of the fire as rapidly as practicable up to just below their melting point. During this operation they should be repeatedly turned over and over so as to insure a uniform high heat throughout the whole end of the tool. As soon as each tool reaches its high heat, it should be placed with its nose under a heavy air blast and allowed to cool to the temperature of the air before being removed from the blast.

1009 Unfortunately, however, the blacksmith's fire is so shallow that it is incapable of maintaining its most intense heat for more than a comparatively few minutes, and, therefore, it is only through these few minutes that first-class high speed tools can be properly heated in the smith's fire. Great numbers of high speed tools are daily turned out from smiths' fires which are not sufficiently intense in their heat, and they are therefore inferior in red hardness and produce irregular cutting tools.

COKE FIRE PREFERABLE TO SOFT COAL FOR HEATING TOOLS CLOSE TO MELTING POINT IN AVERAGE SMITH SHOP

1010 On the whole, a blacksmith's fire made from coke may be regarded as better for giving the high heat to tools than a soft coal fire, merely because a coke fire can be more easily made by the smith which will remain capable for a longer period of heating the tools quickly to their melting points. We have, however, recently made some very careful experiments in which, out of a lot of tools made from practically the same steel, each alternate tool was heated in the best type of coke fire and the best type of soft coal fire, and in every case a notably better tool was produced by the first-class soft coal fire. An improvement of fully 4 to 8 per cent was made by the soft coal over the coke tools. This is undoubtedly due to the fact that a first-class soft coal fire liberates large amounts of hydro-carbons which give an intense heat and are less likely to oxidize the steel than a correspondingly hot flame produced from coke.

1011 Nevertheless, for the reasons given above, our advice is to use a coke fire and make it as deep as practicable. This is for the sake of securing uniformity. We have found it practically impossible to prevent smiths from giving tools their high heat in the soft coal fire long after the fire has passed that period of intensity which is suited to the high heat treatment. When the air blows through the fire and

strikes the hot tool, it appreciably injures the outer layers of
steel to the depth of from $\frac{1}{16}$ inch to $\frac{3}{16}$ inch.

1012 Cooling a tool in an air blast from high heat will produce
good and uniform a tool as can be made by any other method outs
of that of plunging it into the hot lead bath, as described in pa
graphs 985 to 988.

1013 All of the more rapid methods of cooling the tool, eit
through plunging it into water or oil, render the tool more liable
fire cracks, and also more brittle in its body and liable to break
service, particularly when there is any lack of uniformity in the he
ing, and at the same time cooling in water or oil gives no greater deg
of "red hardness" than can be obtained through blowing in the
And this applies without exception to all steel of the chemical cc
position suited to making the better modern high speed tools.
attention whatever need be paid to any other special directions gi
by the makers.

1014 The one question about high speed tools which more than
other has been asked the writer for years past is: "Where can absolut
uniform high speed tool steel be bought?" and the writer's invaria
answer has been: "Any one of the first-class makes of high sp
tool steel is amply good. The trouble does not lie with the lack
uniformity of the tool steel. The main trouble is that you have
yet stolen the whole of the invention. You had better go back
steal it all."

1015 Several types of apparatus have been developed for giv
high speed tools their first or high heat treatment as well as for giv
them their second or low heat treatment. For a description of so
of these the writer would refer to Mr. Gledhill's admirable pa
above mentioned, on "The Development and Use of High Speed T
Steel," and also to an article by Messrs. O. M. Becker and Wal
Brown in the "Engineering Magazine" for November, 1905.

IMPORTANCE OF NOT OVERHEATING HIGH SPEED TOOLS IN GRINDI

1016 The writer trusts that he has made the fact clear that
property of red hardness in tools is seriously impaired by even te
porarily raising their temperature beyond 1240 degrees Fahr.
ventures to say that fully half of the high speed tools now in use
the average machine shop have been more or less injured, and
therefore lacking in uniformity, owing to their having been ov
heated during the operation of grinding. Even when a heavy stre
of water is thrown upon the nose of the tool throughout the operat
of grinding, tools can be readily overheated by forcing the grind

or by allowing the tool to fit against the grindstone, as explained in paragraph 481. This injury is all the more serious because there is no way of detecting it except by finding through actual use that the tool has become of inferior quality. The writer has frequently seen tools which were ground under a heavy stream of water heated so that the metal close to their cutting edges showed a visible red heat.

1017 Occasionally tools are also overheated by running at too high speeds in the lathe. In this case, however, the injury to the tool is perfectly apparent, and therefore not so serious as the overheating on the emery wheel.

1018 A tool which has been overheated either in grinding or in the machine can be again rendered first-class in quality by grinding it from $\frac{1}{16}$ inch to $\frac{3}{16}$ inch back from the cutting edge and down from the lip surface, because overheating from grinding or running in the lathe rarely penetrates beyond this depth.

1019 The best advice that we can give to those desirous of having uniform tools is not to experiment with new brands of tool steel. Adopt once for all the best that can be had at the time the choice is made, and then see to it that the smith heats each tool uniformly and rapidly close to the melting point, and that the grinder does not overheat the tool in sharpening it. Watch the smith and the grinder, do not change the make of the tool steel.

THE CHEMICAL COMPOSITION OF TOOL STEEL

FOLDER NO. 20 GIVING THE ANALYSES AND CUTTING SPEEDS OF MANY OF THE LATEST HIGH SPEED TOOLS, AND A COMPARISON OF THESE TOOLS WITH MUSHET SELF-HARDENING TOOLS AND THE ORIGINAL HIGH SPEED TOOLS AS DEVELOPED BY MESSRS. TAYLOR AND WHITE

1020 The best tool steel should be capable of producing high speed tools of the following qualities or characteristics:

LIST OF THE MORE IMPORTANT CHARACTERISTICS OF HIGH SPEED TOOLS

1021 (A) Tools should be of such composition that comparatively small errors or imperfections in the heat treatment will not seriously injure them and thus render them irregular in their cutting speeds. That is, the steel should be of that composition from which it is easy to make uniform tools.

1022 (B) Tools should not fire crack easily from the heat treatment.

1023 (C) Tools should be capable of running at the highest sta ard speed in cutting either hard, medium, or soft steel; or ha medium or soft cast iron.

1024 (D) Tools should be difficult to ruin on the grindstone through overheating in the lathe.

1025 (E) Tools should be tough in the body; *i. e.*, not liable break in use even when receiving severe jars or blows from the wc

1026 (F) Tools should be capable of taking fine feeds in cutt hard metals with proportionally high cutting speeds as when tak coarse feeds.

1027 (G) Tools should be easy to dress or shape without requir very high heat.

1028 (H) When injured through use in the lathe, the quality the tool steel should be such that the injury can be repaired by gri ing off as small an amount as practicable from the tool.

1029 No tool steel has yet been developed which possesses al these qualities in the highest degree. It is, however, a most inter ing and useful fact that the tool steel marked No. 1 in Folder Table 128, possesses all except two of these qualities in as high a deg as any steel that we have tested. The two defects possessed by t steel are that it is rather difficult to forge into a tool; and although i very tough in its body, it is not as tough as tools whose bodies either annealed or partially annealed.

CHEMICAL ANALYSES AND CUTTING SPEEDS OF THE BEST MODERN H SPEED TOOLS

1030 In Folder 20, Table 128, we give the chemical compositio various makes of tool steel now in use, and we believe that this contains the most noted, and as far as we know the best Engli German and American brands of high speed tool steels. Oppo each make of tool will be found its standard speed, 20 minu duration, $\frac{3}{16}$ inch depth of cut, $\frac{1}{16}$ inch feed, in cutting:

a Medium tool steel about 0.34 per cent carbon, 73,000 l tensile strength, 30 per cent stretch;

b very hard annealed tool steel, about 1 per cent carb 100,000 lbs. tensile strength, 6 per cent stretch; and

c very hard cast iron.

1031 It has been our experience that a tool capable of cutt metal of these three qualities at high speeds is also capable of cutt at correspondingly high speeds almost any other quality of steel

; iron which is softer than those given. Tools are sometimes nd which will cut the very hard metals at high speeds, and yet not roportionally well on the medium metals; but if they cut both the y hard and the medium, our experience is that they are equally d for anything softer. Many tools can be found, however, which softer metals well and yet fall down badly in cutting hard steel hard cast iron.

1032 We are just completing (October 20, 1906) a series of tests h the tools upon the forgings and castings just referred to. In dition to this we have tested in cutting the same pieces of metal the l fashioned carbon tools of the Jessop make; two Mushet tools, one d by us in our former experiments, and the other an especially e quality of Mushet tool dating back to the early 90's; also ols used by us in our experiments for developing the Taylor-White rocess, which resulted in high speed tools. In addition to these, we ave also tested upon the same forgings and castings some of the tools ed by us since the Bethlehem experiments in determining the laws r cutting metals referred to in paragraphs 770 to 814; and some of he tools used by us in experiments made since the Bethlehem experiments to determine the chemical composition of those high speed-ols which at that time ranked first.

RECENT COMPARISON OF CUTTING SPEED OF BEST MODERN HIGH SPEED TOOLS WITH THAT OF FORMER TYPICAL TOOLS

1033 Our objects, then, in making the series of experiments whose esults are tabulated on Folder 20, Table 138, are first, that having letermined the best steel to use for making modern high speed tools, e might clearly connect this information with practically all of our ast experiments. (This is important principally for the purpose of odifying all of the laws and formulæ obtained by us, so as to bring hem completely up to date and make them accord with the tools ade from the best tool steel now known), and second, because as an teresting historical fact, they indicate as accurately as practicable e progress made in proceeding step by step from the carbon tools the best modern high speed tools.

E BEST CHEMICAL COMPOSITION FOR MODERN HIGH SPEED TOOLS

1034 By referring to Folder 20, Table 138, it will be noted that while .1 tool is in all respects better than any of the others, yet the differ-es in cuttingspeeds are comparatively small between this tool and

several of those following it. Therefore the users of tool steel cannot go far wrong by adopting any one of these noted brands of tool steel, but having once adopted a make of tool steel we would strongly advise against changing, and particularly against allowing any other steel to be used in the same shop.

CARBON TOOL STEELS

TABLE GIVING THE ANALYSES OF SELF-HARDENING AND ORDINARY CARBON TOOL AS USED BEFORE THE DISCOVERY OF HIGH SPEED TOOLS

1035 Folder 22, Table 140, affords an interesting study of the relations between the chemical composition of various tool steels and their cutting speeds. Beginning with the analyses of carbon tool steels, by referring to Folder 22, Table 140, Nos. 85 to 89, it is apparent that but small differences exist in the cutting speeds of the various makes; in fact, when cutting the same quality of metal, the cutting speeds do not vary more than 6 per cent.

TOOLS WHICH ARE NOT SELF-HARDENING AND YET CONTAIN TUNGSTEN OR CHROMIUM

1036 Analyses Nos. 82 to 84 include several tools which must be hardened and tempered in the old fashioned way to be of any use; and yet to these steels have been added the two metals which when combined in sufficient quantities produce self-hardening tools. A study of the chemical compositions of these steels is chiefly interesting for two reasons:

1037 First, because they illustrate the fact that the presence of tungsten even to the extent of 7 per cent as in the case of No. 83 (the Eicken) produces a tool which has no more self-hardening properties than ordinary carbon steel, the reason for this being that there is but an exceedingly small amount of either manganese or chromium present; and also that, as in the case of No. 84 (Midvale chrome-crucible), a tool may contain 1.6 per cent of chromium (an ample percentage to make good self-hardening steel if either tungsten or molybdenum were present) and still have no self-hardening properties.

1038 Second, because they show clearly that the addition of 1.6 per cent of chromium coupled with 0.71 per cent of carbon (a very low carbon for a tempered tool steel) and also with 0.10 per cent manganese (a decidedly low manganese for a tempered tool steel) gives the tool a

materially higher cutting speed than that of the ordinary carbon tempered tools.

1039 We made a very exhaustive examination of this steel, but the fact that it required more skill on the part of the blacksmith in judging its proper hardening heat than the ordinary carbon tools prevented its adoption as a standard shop tool, even although tools of this composition could be run at a cutting speed materially higher than the carbon tempered tools. The cutting speed of these tools was about halfway between that of the carbon and the self-hardening tools; but if heated a little too high they were apt to fire crack in hardening, and our experience with fire cracks in tools leads to the conclusion that great damage is likely to be done through their breaking in daily use. Therefore when a steel, either carbon, self-hardening, or of the modern high speed tool variety, shows any marked tendency to fire crack or toward brittleness, we promptly abandon all idea of its adoption as standard. The writer calls attention to this fact chiefly because later, in considering the more important question of the proper chemical composition for high speed tools, it will be observed that many tools whose cutting speeds and other qualities entitled them to consideration were promptly abandoned because they showed a marked tendency toward fire cracking or brittleness.

1040 However, the steel represented in Analysis 83 excels in one respect all carbon steels which have come to our attention. It is admirably suited to finishing extremely hard metals, and, in spite of its requiring a low hardening heat, is an excellent standard for this special purpose.

1041 On Folder 22, Table 140, Nos. 65 to 81, we give the analyses of several self-hardening tools made between the dates of 1893 and 1898; and of these, Nos. 65, 66, 67, 68, and 33, were experimented with by us at the Bethlehem Steel Company just prior to the discovery of the Taylor-White process while searching for the best self-hardening steel to adopt as a shop standard for that company. Many other brands of self-hardening tools had been tested previously by us as to their cutting speeds but because of evident inferiority to the above brands were not analyzed or tested at this time. These five makes of tool steel, then, are interesting because they represent, so far as we know the best self-hardening steels then in the market, and the only makes which we believed to be worthy the expenditure of time and money required in making careful standard speed tests on the experimental lathe. It is notable that two steels out of the five (Mushet and Firth-Stirling) depended for their self-hardening properties upon a comparatively large percentage of manganese in com-

bination with tungsten, while three of them depended mainly upon high chromium in combination with tungsten or molybdenum. It will be observed that No.68 (Midvale) gave the highest cutting speed, but, as explained in Part 1, paragraphs 106 to 109, this steel was seriously injured in the operation of heating by the blacksmith, which injury led to the discovery of the Taylor-White process. It is highly likely, therefore, that had not the high speed tools been discovered the Mushet self-hardening steel No. 68 would have been adopted by us as our standard in spite of the slightly higher cutting speed of the Midvale steel, since, as explained, the Mushet steel gave evidence of overheating by the blacksmith through crumbling when hammered. Thus the Mushet tools, when injured by overheating, remained in the blacksmith shop, while overheated Midvale tools were likely to get into the machine shop and interfere seriously with the uniformity in the shop tools.

TABLE GIVING ANALYSES AND CUTTING SPEEDS OF VARIOUS TOOLS EXPERIMENTED WITH BY MESSRS. TAYLOR AND WHITE IN THE DISCOVERY AND DEVELOPMENT OF THE NEW HIGH SPEED TOOLS

1042 On Folder 21, Table 139, are given the chemical compositions of various steels experimented with by us during the time of the discovery and development of the new high speed tools by Mr. White and the writer. These tools are separated into various groups for the purpose of showing the relative effect of comparatively large and small quantities of each of the following elements upon the cutting speed; namely, tungsten, molybdenum, chromium, carbon, and manganese.

1043 After the columns giving the percentages of the various ingredients of which the tools are composed, two columns are found, in the first of which is entered the cutting speed of the steel when given the ordinary heat treatment as practiced before our invention, and as in many cases recommended and even superintended by the makers of the tool steel. In the second column are entered the speeds obtained by the same tools after having been treated carefully by the Taylor-White process of heating the tool close to the melting point, cooling it and then reheating it to about 1150 degrees Fahr.

1044 A study of the various groups of tools together with their cutting speeds before and after receiving the high heat treatment will make clear the basis of our claim in Patent No. 668269, that tools containing one half of one per cent or more of chromium and one per

cent or more of tungsten, or its equivalent in molybdenum, are materially improved in cutting speed through the treatment by the Taylor-White process. This, however, is of minor interest. A subject of greater interest is the effect of the various elements when used in such quantities in the tool steel as to produce tools of the highest cutting speeds; that is, the highest degree of red hardness, when treated by the Taylor-White process.

DISCUSSION OF THE EFFECT OF EACH OF THE FOLLOWING ELEMENTS UPON HIGH SPEED TOOLS AS ORIGINALLY DEVELOPED— TUNGSTEN, CHROMIUM, CARBON, MOLYBDENUM, MANGANESE, SILICON

1045 By examining the chemical compositions of the tools given after Nos. 26 to 35 (namely, the groups of tools which after receiving the Taylor-White treatment gave the highest cutting speeds during the period of our invention), it will be noted, first, that no tool in this group contains less than 6½ per cent of tungsten and that the highest tungsten in this group is 8.75 per cent; second, that no tool in this group contains less than 1.62 per cent of chromium, and that the highest chromium is 3.94 per cent. It would seem, therefore (as a result of these investigations), that to produce what we considered at that time first class tools, the chromium and tungsten must be within these limits.

1046 The effect of low tungsten will be seen by examining tools Nos. 41 to 44. In No. 42 it will be noted that with 1.91 per cent of tungsten and 3.25 per cent of chromium, a tool was produced which improved materially upon being heated to a high heat, whereas tool No. 41 containing 0.83 per cent of tungsten and 3.80 per cent of chromium deteriorated materially in its cutting speed upon receiving the high heat treatment. From this it is evident that even with high chromium more than 0.83 per cent of tungsten is required in the tool before the property of red hardness begins to be apparent, and also that high chromium tools are injured in their cutting speeds when overheated, although of course not to the same extent as ordinary carbon tools.

1047 On the other hand, upon examining the carbon column we note that the lowest carbon which produced a first-class tool was 0.858 per cent while the highest carbon was 1.950 per cent. Between these limits, then, our experiments indicated that, as far as the effect of cutting speed was concerned, it was a matter of indifference whether low or high carbon was used. And it is a notable fact that many of the

best high speed tools developed up to the present date contain carbon, in almost the same percentage as that indicated by the low limit in our experiments.

1048 At the time that we were developing our invention it was not usual to make self-hardening steel containing carbon in as small quantities as 0.86 per cent. An increase of carbon produces an increase in the hardness of a self-hardening tool, although, as indicated by the group of tools from No. 26 to No. 32, increasing carbon beyond 0.86 per cent does not produce a higher cutting speed or a greater degree of red hardness which is the distinctive quality of high speed tools. We had the 0.86 per cent carbon steel made especially for the purpose of testing the effect of low carbon upon red hardness in Taylor-White treated tools. And it was the statement made in our patent, that high heat treated tools containing 0.86 per cent of carbon gave as high cutting speeds as those containing high percentages of carbon, which first turned the attention of makers of tool steel in this direction.

1049 Our adoption of the higher limits of carbon at the time of the writing of the Taylor-White patent was upon the supposition that through heating the tool many times in succession to the high heat, the carbon lying in the outer layers of the nose of the tool might be considerably reduced, and that with high carbon this reduction of carbon would leave the tool as efficient as ever, whereas with carbon as low as 0.86 per cent any material reduction in carbon might affect its cutting speed.

1050 However, more recent experiments have shown that even with comparatively low carbon there is little danger of injuring the tool so that it cannot be repeatedly heated to the high heat from oxidization or burning out of the carbon in the outer layers of the tool; and in the best of the present high speed tools the rather low carbon of 0.68 per cent is used for the purpose of rendering the steel more readily forged to the proper shape, and also to make it rather less brittle in the body of the tool.

1051 Referring to the manganese column, it is notable that the lowest manganese is 0.07 per cent and the highest 1.19 per cent. It is clear then that low manganese does not affect the property of red hardness in high speed tools. Low manganese renders the tool stronger in its body, less liable to brittleness, less liable to fire crack, and more easily forged and annealed; and for this reason we recommended a steel low in manganese as best for the Taylor-White treated tools.

1052 By examining Folder 21, Table 129, the three groups of analyses, namely, the effect of high chromium and the effect of low chro-

nium and the effect of low manganese, it will be noted that making a tool of high chromium with the proper amount of tungsten invariably produces a high speed tool even although the manganese is low; but that a tool without chromium or with very low chromium, even though there is a proper percentage of tungsten present, does not produce a high speed tool even though the manganese may be low or very high. From this it follows that chromium is the element which in combination with tungsten produces the new quality of red hardness and not manganese.

OLYBDENUM AS A SUBSTITUTE FOR TUNGSTEN IN HIGH SPEED TOOLS

1053 Mr. White and the writer stated in our patent that molybnum can be substituted for tungsten in modern high speed tools, d that one part of molybdenum will produce approximately the me effect as two parts of tungsten. We also stated that molybnum is not as satisfactory an element as tungsten to use in high eed tools. The writer would repeat these assertions as giving our ews at the present day upon the use of molybdenum in high speed ols.

1054 By referring on Folder 21, Table 129, under the head of "Molybnum substituted for tungsten" to the tools Nos. 55 (at the top of e list), to 63 inclusive (at the bottom of the list), it will be noted at, particularly in the case of tools Nos. 43, 54, 50, and 61, molybnum tools having high cutting speeds were experimented with during e development of the Taylor-White process, and that from 4 per cent 4½ per cent of molybdenum appeared to be a sufficient quantity to ake a high speed tool; whereas about 8 per cent of tungsten was quired for this purpose. However, by noting our remarks made ter most of these tools, it will be seen that they were brittle, had a ndency to fire crack, were weak in the body of the tool, or else they ere irregular in their cutting speeds. All of these faults are most rious in their nature, and they were at that time and are still garded by us as so serious that when a tool clearly develops any one thes troubles we at once cease experimenting with it as not orthy of consideration among first-class tools.

1055 The irregularity in molybdenum tools constitutes perhaps s most characteristic feature. By irregularity we mean that tools the same chemical composition, and apparently treated alike, give rge variations in cutting speed. We have as yet been unable to etermine with certainty the cause for the irregularity existing in olybdenum tools. One explanation, however, for this trouble may

lie in the fact that molybdenum tools appear to run at their highe cutting speeds when given a high heat slightly lower than the hi heat required to produce a first-class tungsten-chromium tool. may be that when the molybdenum tool is heated beyond that preci high heat which is necessary to make a first-class tool, it deteriorat

1056 One of the most useful characteristics in the modern tungste chromium high speed tool is that, providing an intensely hot fire available, it requires little or no skill on the part of the blacksmi to heat it up close to the melting point, and that the tool itself sho clearly by its appearance when its high heat has been reached. Mo over, it is impossible to injure the cutting properties of these to even if they are heated to a point at which the thinner or sharp edges begin to melt. The difficulty of judging by the eye an exa high temperature reached by a tool when close to or at its melti point is so great that if a definite treating temperature were requir at these very high heats,—that is, if tools were injured by heati beyond this temperature,—much of the value of the high speed to would be lost.

1057 Now, as stated, it appears likely that the irregularity molybdenum tools may be largely due to the fact that a more accura degree of high heat, considerably below their melting point, is requir for them, and that this temperature must be closely judged by t eye of the smith, while no accurate judgment is required for t tungsten-chromium tools, because the tools themselves show wh they are close to the melting point; and close to or at the melti point is the temperature which produces a tool giving the highe cutting speeds.

BEST MODERN HIGH SPEED TOOLS COMPARED WITH ORIGINAL HI SPEED TOOLS DEVELOPED BY US

1058 It will be a matter of interest to compare the various pro erties and chemical compositions of high speed tools as develop by us at the time that our patent was written with those of the best the high speed tools that have been made up to the present tin Tools Nos. 26 and 27, Folder 21, Table 129, are those recommended our patent. By referring to their speeds in cutting, on the o hand, a medium steel, and on the other hand, very hard steel an hard cast iron, it will be seen that tool No. 26 gave the higher cutti speeds on hard steel and cast iron, while tool No. 27 gave the high cutting speeds upon medium and soft steels. Thus, at the time the writing of our patent, in order that a machine shop should ha

the best tool equipment it was necessary that tools made of two different chemical compositions be maintained as standards.

1059 Referring now to tool No. 1 the best high speed tool experimented with by us in 1906, it will be noted that it has a higher cutting speed upon all the qualities of metal experimented with than any other tool. One of the gains, then, made by the latest high speed tools lies in the fact that in one tool steel are combined all of the most desirable properties, and therefore tool steel of only one chemical composition need be adopted in a shop as standard.

1060 We have referred in paragraphs 965 to 968 to red hardness as the distinctive property of modern high speed tools, and on Folder 4, Fig. 18, we show a photograph of a tool possessing in a high degree red hardness, while at the same time it is so soft that it has been readily filed after running successfully at very high speed. Now while red hardness is the most important property or quality sought for in high speed tools nevertheless, for certain classes of work, namely, turning the very hard qualities of steel and also hard cast iron, the property of hardness is desirable in addition to that of red hardness. The principal difference between tools Nos. 26 and 27 is that the former combines the quality of red hardness with hardness, while the latter lacks somewhat the quality of hardness, although it possesses red hardness in a higher degree than No. 26. The reason, then, that No. 26 cuts hard steel and hard cast iron at so much higher cutting speed than No. 27 is due to the fact that it adds the quality of hardness to that of red hardness. It must be borne in mind, however, that in the average machine shop more than nine-tenths of the work is done upon the medium or softer qualities of metal. Therefore, it is only upon a comparatively small class of work that the quality of great hardness needs to be added to that of red hardness in high speed tools.

1061 One property in which tools Nos. 26 and 27 were both lacking was that, although in cutting soft metals they made the same proportionate gains in cutting speed when taking the fine feeds as when taking the coarser feeds, still when these tools were cutting steel of even medium hardness, but slightly higher cutting speed could be used with a feed finer than $\frac{1}{16}$ inch than could be taken with a feed of $\frac{1}{16}$ inch. This presented a really serious defect in our high speed tools because the greater portion of the feeds taken in the machine shops are finer than $\frac{1}{16}$ inch.

1062 As referred to in paragraphs 816 to 828, tools of chemical composition of No. 1 were proved in our recent experiments (1906) to be capable of making the same proportionate gain in cutting very hard metals with fine feeds as they made when cutting soft metals with fine

feeds. This then represents a second feature in which the latest high speed tools are better than those originally developed; and this property is also due to the fact that the latest tool possesses a high degree of hardness in addition to its very extraordinary degree of red hardness. In the quality of hardness, however, it will be noted that tool No. 1 does not outstrip its nearest competitors to the same extent as it does in its extraordinary quality of red hardness, the gain in cutting medium steel being proportionally larger than the gain in cutting hard metals.

1063 The third feature in which tool No. 1 is superior to tools No. 26 and 27 is that it is stronger in the body.

1064 By far the most important improvement, however, in No. 1 tool over the original tools Nos. 26 and 27 (a matter which the writer looks upon as of even greater importance than the 50 per cent increase in cutting speed) is the fact that it is much more difficult to injure No. 1 tool through carelessness in heating upon the grindstone or through overheating in the lathe under the cut than the original high speed tools. The No. 1 tool will stand a surprising amount of overheating on the grindstone without very serious deterioration; whereas Nos. 26 and 27 were exceedingly sensitive to this bad treatment, and perhaps to this cause more than any other is to be attributed the great lack of uniformity in high speed tools which existed in the early years of their adoption. For this reason, then, No. 1 tool marks a most important advance in maintaining the all important quality of uniformity.

1065 In our patent and in writing this paper we have referred to the good effects resulting from the second or low heat treatment. The percentage of increase in cutting speed due to the second or low heat treatment was more marked in the case of our original high speed tools Nos. 26 and 27 (Folder 21, Table 139) than it is in the case of our latest high speed tool, No. 1 (Folder 20, Table 138). With the original high speed tools in many cases our low heat or second treatment resulted in a gain in cutting speed of as much as 30 per cent while in tools of the type of No. 1, the second treatment rarely resulted in a gain of more than 10 per cent and frequently even not so large a percentage as this.

1066 On the whole, we look upon this as a very great improvement in the latest high speed tools over the original, because even if the new tools are not given the second or low heat treatment at all, still they will be far more nearly uniform than the original tools of this class. Moreover, among those who have stolen and who are using the process of making high speed tools, by heating tools close to their melting point but very few have used in the past or are now using the

second or low heat treatment except in as far as this treatment is given to the tool through heating it incidentally or accidentally upon the grindstone or through heating it under the pressure of the chip in the lathe. The only feature in which tool No. 1 is less desirable than tools Nos. 26 and 27 is that it is more difficult to forge, at the old forging heats, namely about a light cherry red.

1067 We have already pointed out that the substitution of chromium for manganese in both the old self-hardening steels and in the high speed steels allows the tool to be forged at a heat very considerably higher than the light cherry red without danger of crumbling. In other words, the addition of the chromium and the absence of manganese render the tool just the opposite of what is called "red short"; that is, just the opposite of a liability to crumble when struck with a hammer at a high heat.

1068 It will be noted that tool No. 1 contains from 5½ per cent to 6 per cent of chromium, and this increased percentage of chromium has the very useful effect of allowing the tool to be forged at an exceedingly high heat, in fact, not very far below the melting point. The danger of injuring the tool through oxidization at this extremely high heat is great, however, and we therefore recommend as a forging temperature a light yellow heat. When tools containing from 5½ per cent to 6 per cent of chromium and of the general chemical composition of No. 1 tool are heated to this light yellow heat they are much easier to forge even than the original high speed tools, Nos. 26 and 27, and also easier to forge than such of the tools as lie between Nos. 2 and 23, and which contain less than 5 per cent of chromium. This is an added and a great advantage of No. 1 tool over the other modern high speed tools.

1069 Tools of the composition of No. 1, then, should be forged at a light yellow heat.

1070 To recapitulate, the improvement in the latest high speed tools over the original high speed tool consists in:

1071 (A) Far greater uniformity, owing to less danger of being injured in grinding and in daily use.

1072 (B) 50 per cent increase in cutting speed.

1073 (C) The attainment of almost its maximum cutting speed without the necessity of the second or low heat treatment.

1074 (D) The combination in the same tool of the highest degree of red hardness with a high degree of hardness, thus requiring only one standard high speed tool steel in the shop.

1075 (E) The ability, owing to increased hardness, coupled with

the necessary red hardness, to make the same proportionate gain when cutting with fine feeds upon hard metals as upon soft.

1076 (F) Greater strength in the body.

1077 The only point of inferiority is increased difficulty in forging at a cherry red, and if blacksmiths are taught to forge their tools at a light yellow heat, these tools are easier to forge than the original high speed tools.

1078 In paragraph 973 we have referred to the fact that since writing our patent no improvement whatever has been made in the heat treatment of high speed lathe and planer tools. The all-round gain in the No. 1 tool (Folder 20, Table 138) over the original high speed tool, then, lies entirely in a change in chemical composition. It would seem therefore a matter of interest to point out the change in the composition of these tools, and, so far as practicable, to indicate the cause and effect of the change in each of the improved elements.

PRINCIPAL CHEMICAL CHANGES MADE IN BEST MODERN HIGH SPEED TOOL OVER ORIGINAL HIGH SPEED TOOL DEVELOPED BY MESSRS. TAYLOR AND WHITE

1079 Our patent, describing the original high speed tool, claims, briefly speaking, the combination of one-half of one per cent of chromium, or more, with one per cent of tungsten, or more; the tool to be treated to the high heat, etc. In our patent we also state that, practically speaking, the best tools developed by us at that time contained 2.00 per cent to 3.80 per cent of chromium instead of 0.5 per cent of chromium, and 8.00 to 8.50 per cent of tungsten instead of 1.00 per cent of tungsten.

1080 The principal chemical change which has taken place in the best high speed tools up to the present time has been to still further increase the percentage of chromium, so that instead of containing 3.80 per cent as recommended by us, the tools now contain from 5.50 per cent to 6 per cent and to still further increase the tungsten from 8.50 per cent to from 18.0 per cent to 19.0 per cent. This large increase in the percentage of chromium and tungsten has produced the material increase of 50 per cent in the red hardness of the tool and at the same time, also, a material increase in the hardness over our original high speed tool No. 27. It is notable, however, that if the percentage of tungsten is increased much beyond 19.0 per cent even although the chromium is also increased in quantity, that the tool diminishes in red hardness. This fact will be noted by comparing the cutting speeds of No. 14 tool (which contains 24.64 per cent of tungsten and 7.02 per

nt of chromium) with the cutting speed and chemical composition f No. 1 tool; and the metal close to the cutting edges of tools containing ese very large percentages of tungsten and chromium appear to eld, or become slightly deformed, particularly when cutting the inner shavings or chips.

1081 The presence of high manganese in a tool and also the presence high carbon, both tend to increase the hardness of the tool. They ke the tool more brittle in the body; and in addition, high manga- se causes the tool to crumble in forging when heated much beyond right cherry red. It was for this reason that we, in our original ylor-White tools, specified low manganese (0.15 per cent); and this been adopted as a characteristic in all the modern high speed ls.

1082 The tools as recommended in our patent contained carbon the extent of 1.85 per cent, and this element has been lowered in dern high speed tools largely as a result of the fact pointed out by us ur patent, that the quality of red hardness is not materially affected either high carbon or carbon as low as 0.86 per cent. If either manganese or high carbon (as much as 1.85 per cent) were used in ol in combination with 5½ per cent of chromium and 19.0 per of tungsten, the tool would be brittle in the body and exceed- y difficult to forge; and the presence of high manganese partic- ly would tend to reduce rather than to increase its red hardness. refore, the latest high speed tools contain manganese in as small ntities as is practicable when the expense of the mixture and the ls in melting are considered.

1083 Modern high speed tools have been recently experimented by us containing carbon varying from the small amount of 0.32 cent to the higher percentage of 1.28; and our conclusion from e experiments is that the property of "red hardness" in the modern speed tools is not noticeably affected by either high or low car- within these limits. The quality of hardness, however, in the tool fected by the percentage of carbon and, as previously explained, ertain degree of hardness is required as a property in high speed ls for several reasons.

1084 The carbon contents of the modern high speed tools, then, ld seem to be governed by a compromise between the two require- nts: on the one hand, higher carbon is needed to produce a greater ree of hardness in the tool; and, on the other hand, lower carbon eeded to make the tool more readily forged and also to make it nger and tougher in the body.

1085 As indicated on Folder 20, Table 138, analysis of tool No. 1,

the best tool experimented with by us contained 0.68 per cent car and we recommend for a modern high speed tool not less than half of one per cent (0.5 per cent).

1086 There is one element of less importance than those pi ously considered which nevertheless should receive attention. statement has been published several times that high silicon ter toward higher cutting speeds in high speed tools. In developing patent, we experimented quite thoroughly with this element, arrived at the conclusion that high silicon tended toward slower ting speeds, particularly when cutting the harder metals. In patent, therefore, we recommended the low silicon, 0.15 per cent, it will be noted that, on the whole, low silicon is a characteristi most modern high speed tools.

1087 Our experiments indicate that high phosphorus and sul are much less injurious to high speed tools than they were to the bon tools. However, these elements still exert a somewhat inju influence upon the steel, and we therefore recommend, inasn as the presence of chromium and tungsten in large quantities n sarily render high speed tools very expensive, that the best qual of low phosphorus and low sulphur iron should be used in their m facture.

DISCOVERY BY MESSRS. TAYLOR AND WHITE THAT SMALL QUANTI OF VANADIUM IMPROVE HIGH SPEED TOOLS

1088 No manufacturer of tool steel needs to be informed that chemical analysis of steel (at least those analyses which are ordin made in our best chemical laboratories) is not alone a true or infal guide to the real quality of steel. There are other factors than elements which are ordinarily determined in laboratories which a the quality of the tool steel.

1089 We all know that to obtain the best quality of tool steel mixture must be melted just right. The melting must be thorough complete in order to bring about the proper alloying of the tung and chromium with the iron and carbon without at the same oxidizing the bath. In addition to this, the metal must be poure "teemed" in the right way in the molds, and the ingots must be mac the best size and shape for the subsequent operation of hammering steel. The steel itself must be also carefully heated and handled ing the operation of hammering. All of these elements affect quality of the steel as does its chemical composition.

1090 An examination of the tools between No. 1 and No. 1

ler 20, Table 138, will illustrate this fact; *i. e.*, that something other a the chemical composition modifies the cutting speed of these s. This will be particularly noted by comparing the analysis of No. 3 with that of tool No. 5. These steels chemically resemble h other very closely, and yet No. 3 has a distinctly better cutting ed than No. 5.

091 Perhaps the most important of these collateral elements or uences affecting the quality of tool steel, however, is that of the ting and pouring or teeming of the ingot in such a way as to ove as far as possible those chemical impurities which are not icated by the ordinary chemical analyses; and of these impurities believe that the more obscure oxides constitute the worst enemies of el. The term "good melting" might be translated into more scien- language by saying that the steel should be so carefully mixed and ted as to contain the minimum quantity of these injurious oxides. re have been various expedients adopted by makers of tool steel to ure this end, and some of these are still held more or less as trade rets. It is our belief, however, that we have discovered during the t year perhaps the most efficacious remedy for "bad melting" that yet been devised. We refer to the use of vanadium, a metal com- ratively new in the art of practical steel manufacture. Mr. James Gledhill, in his paper on "The Development and Use of High ed Tool Steels" published in the "Journal of the Iron and Steel stitute," in 1904 speaks of having substituted vanadium for romium in high speed tools, and he states that while the vanadium en used in cutting a steel of medium hardness stood well, yet it l not do better than tools containing the element of chromium.

092 Our experiments indicate the fact that vanadium should not substituted for chromium, but that a very minute quantity of nadium should be added to the mixture in melting, and that its use the extent of from 0.15 per cent to 0.35 per cent is as effective as ger quantities in the mixture. Our experiments would indicate probability that the good effects of vanadium are derived from its mical property as a cleanser of the steel during the operation of lting rather than as a very valuable property in the steel after it is lted. From 0.15 per cent to 0.30 per cent of vanadium when ed with the steel in the pot sometimes disappears entirely from finished steel, and its presence cannot be found by analysis, indi- ing that it has probably joined with some other element or ele- nts, and gone off into the slag. It is likely then that minute quan- ies of vanadium act as cleansers of the bath, uniting with some of obscure oxides and carrying them off into the slag. We know, for

example, that the shop in which No. 1 tool (Folder 20, Table 138) was made is not run with the exceptional skill of long experience, and yet in this shop the addition of small quantities of vanadium very materially improves the cutting properties of the tool.

1093 An illustration of this fact will be seen by comparing steel No. 18 with steel No. 19, these two steels being practically the same chemical composition except that one of them has had a small amount of vanadium added to it. These samples of steel were made in the melting shop above referred to.

1094 To close the subject of the chemical composition for high speed tools, we do not wish to give the impression that we believe that No. 1 tool represents the chemical composition of the best tool which will ever be made. On the contrary, we believe that the improvement in the proper combination of the various elements required to make a high speed tool will continue, and it is a matter of surprise to us that greater improvement has not been made since our original discovery of high speed tools. Manifestly, it is highly desirable that a mixture should be found for high speed tools which shall be much more economical than any of the mixtures now used; and we believe that in the future this result will be brought about. It would seem as though this presents perhaps the most important field for the future economical development of the high speed tool.

THEORY OF HARDENING STEEL

INVESTIGATIONS MADE TO FIND AN EXPLANATION OR THEORY FOR THE PHENOMENA CONNECTED WITH "CHROMIUM TUNGSTEN" HIGH HEATED TOOLS

1095 The facts regarding the effects of heat treatment on "chromium tungsten" and "chromium molybdenum" tools have been carefully investigated, and recorded as above. As yet, however, no theory has been advanced which in the judgment of the writer explains these phenomena. Investigations were made on this subject by Otto Böhler, of Austria in 1903, and published in an article by him entitled "Wolfram und Rapid Stahl." Several articles have been written also by Messrs. Osmond and H. LeChatelier, both of whom are among the most careful and scientific investigators in the metallurgical field, and valuable data is given by Mr. J. E. Stead, in his contribution to the discussion in the Report of the Alloys Research Committee of the Institution of Mechanical Engineers; but the most thorough and up-to-date investigation which has come to the writer's attention is

that made by Prof. H. C. H. Carpenter, Ph. D. of the National Physical Laboratory in England, and published in the "Journal of the Iron and Steel Institute," 1905, p. 433. In their papers on this subject all of these writers, however, assume that the reader already has a certain familiarity with the subject, and they use without definition, words and certain technical expressions and even conventional symbols which render their writings more concise and more simple but only to one who has read much that has previously been written. These special technical expressions make it difficult for even an educated engineer to clearly understand their articles without very considerable study. The present paper is intended not only for engineers familiar with the subject, but more especially for shop superintendents, managers and foremen, many of whom have but small familiarity with the scientific or metallurgical side of the problems. The writer will, therefore, endeavor to give in simple words an explanation of some of the more important phenomena developed by these gentlemen.

1096 Carbon or tempered tools are made from tool steel containing from $\frac{75}{100}$ of 1 per cent up to about $1\frac{1}{2}$ per cent of carbon. In addition, this class of tool steel contains small quantities of silicon, manganese and, unfortunately, phosphorus, and sulphur. The hardness of tools made from this class of steel, however, depends mainly upon the carbon, and carbon exists in tools, broadly speaking, in two conditions or states; one of which may be called the *hardening carbon* and the other the *softening carbon*. The technical names given to these two conditions being martensite and pearlite, a bar of this carbon tool steel as it is received from the maker contains carbon practically all in the softening state. After the tool is forged to shape, in order to harden it, as is well known, it must be heated above a certain definite temperature. This temperature varies according to the amount of carbon, manganese and silicon which are present in the tool steel; but, in general, it is fairly close to 1450 degrees Fahr. (786 degrees C.). When these tools are heated slightly beyond 1450 degrees Fahr. (786 degrees C.) the softening carbon is changed entirely into hardening carbon, and it takes a certain interval of time for this change in the form of the carbon to take place. If the tool is then cooled slowly until it is below 1400 degrees Fahr. (760 degrees C.) the form of the carbon is again changed back from hardening to softening carbon. This change backwards and forwards from hardening to softening carbon, or vice versa will take place each time the tool is heated above 1450 degrees Fahr. (786 degrees C.) or cooled below 1400 degrees. Fahr. (760 degrees C.)

1097 It is doubtless due to the fact that the transformation from

the hardening form to the softening form of carbon requires a certain quite appreciable length of time that carbon steel tools can be hardened at all. If tools are heated above 1450 degrees Fahr. (786 degrees C.) and are plunged into cold water, or very rapidly and continuously cooled in any other way, until they arrive at a temperature below about 392 degrees Fahr. (200 degrees C.), at no one period in the process of cooling is time enough allowed for the hardening carbon to change its form into softening carbon, and after the temperature of the tool is below 392 degrees Fahr. (200 degrees C.) the hardening carbon is imprisoned, as it were, in its hard or diamond-like form in the tool, and gives to the whole tool its hardness; and as long as a tool remains below 392 degrees Fahr. (200 degrees C.) the change from hardening back to softening carbon cannot take place. If the process of cooling a carbon steel is halted, however, at any point between the temperature of 1400 degrees Fahr. (760 degrees C.) and that of 392 degrees Fahr. (200 degrees C.) even for a comparatively short time, then to a greater or less degree, the change from hardening to softening carbon will take place.

1098 Tools which have been hardened by sudden quenching from 1450 degrees Fahr. (786 degrees C.) are in most cases too brittle for practical shop use, and they are softened or "tempered" to any desired degree by reheating them above the temperature of 392 degrees Fahr. (200 degrees C.) The higher the tool is heated above this point up to about 600 degrees Fahr. (315 degrees C.) the softer and softer it becomes as the hardening carbon is gradually changed back into softening until at 600 degrees Fahr. (315 degrees C.) it is entirely soft.

1099 Mr. LeChatelier invented an exceedingly sensitive and accurate pyrometer for rapidly measuring the heat at higher temperatures, and investigations made a number of years ago with this pyrometer demonstrated the fact that as the carbon is changed from its hardening to its softening form, so definite and powerful a molecular action or change in the internal structure takes place inside the steel as to actually develop a very considerable amount of heat — Therefore, as a tool which has been heated hot enough to contain carbon in the hardening form is gradually cooled when it reaches the critical temperature 1400 degrees Fahr. (760 degrees C.) at which this internal molecular change occurs, the heat brought about by this molecular disturbance is actually sufficient in many cases not only to entirely stop for a considerable length of time the cooling of the tool but to slightly reheat the tool; and it is for this reason that this point of carbon transformation from hardening to cooling and vice versa has come to be called the "reheating point" the "point of recale-

s" or the "critical point" in the tool steel. The heat which is sloped by this molecular change, however, is not always sufntly great to actually reheat the steel to a higher temperature, ough in all cases it checks and temporarily slows down the rate of ing. For this reason this change point in the carbon is more frentlly called the "critical point," and this would appear to be, on whole, a better name.

100 All tool steels, whether of simple carbon or of the later high d varieties, have at least one critical point, and many of them two ore critical points, in cooling down from a high heat to the normal perature of the air; and it must be remembered that in each case e critical points shown by the cooling experiments indicate that e internal molecular change has taken place. In heating carbon steel the lower critical point is, generally speaking, between 392 r. (200 degrees C.) and 600 degrees Fahr. (315 degrees C.) at ch point softening or tempering is taking place. And the upper ical point, as before explained, occurs at about 1450 degrees Fahr.) degrees C.), at which point softening carbon is changed back into dening carbon. The critical points in heating tool steel, however, not occur at the same temperature as those for cooling, showing t the internal chemical or molecular changes in the carbon or other redients do not occur at the same temperature while the heat is ng upward as they do while the heat is going downward. (See lder 10, Figs. 57 and 58.

1101 By comparing the critical points, Folder 10, Figs. 57 and 58, the heating curves shown at the right hand side of the vertical line th the critical points of the cooling curves on the left hand side, it ill be noted that the principal critical point in heating is higher by bout 160 degrees Fahr. than the principal critical point in cooling. he operator who is hardening carbon steel, therefore, is much more terested in the heating than in the cooling curve, as it is to the former hat he looks to find the critical point just above which he must heat is tool in order that it may harden thoroughly, preserve a fine grain, nd be free from the brittleness and various troubles which come rom overheating.

1102 All of the theorists who write upon this subject practically gree that the hardness of old fashioned self-hardening tools is due rimarily or principally to the presence of carbon in the steels (that f carbon were removed from self-hardening steels they would not e much if any harder than carbon tool steel would be if the carbon ere removed from it); namely, that without carbon all qualities of teel would be soft so far as metal cutting properties are concerned.

1103 We have just pointed out that carbon (in ordinary tool steel) which exists in the "hardening" condition when the steel is heated above the critical point changes in a short time to carbon in the "softening" condition after the tool is cooled below the critical point. A few seconds or minutes, depending upon the size of piece, are sufficient time for the change from hardening to softening carbon to take place in ordinary carbon steel tools.

1104 The theory explaining why the old fashioned self-hardening tools have their property of hardness is that when these tools are heated up to above the critical point and the carbon is formed into the "hardening" state, and they are then cooled below the critical point, the hardening carbon instead of changing quickly to softening carbon (as in ordinary tool steel) becomes tangled, as it were, with the tungsten and manganese, and takes many hours to change from the "hardening" to the "softening" state, instead of a few seconds or minutes, as with ordinary tool steel when tungsten and manganese are not present to any large extent.

1105 A tool, however, after being forged, even if laid down in the air to cool, will cool down to a black heat in a few minutes at most; so that with self-hardening tools in practical, everyday conditions, there is never sufficient time, owing to the tangling or retarding effect of tungsten and manganese, for the carbon to change from the hardening to the softening condition.

1106 We believe that this theory is substantially correct as far as the quality of "hardness" is concerned, but as we shall point out later, it does not at all account for or explain the new property of "red hardness" which is the characteristic of high speed tools. And so far as we know, theoretical writers on the subject have up to this time confused these two properties, speaking of the new property of "red hardness" as though it were the same as "hardness."

1107 Most modern scientific articles which have been written on the hardening and the tempering or softening of steel tools treat mainly of two subjects:

a The crystalline or other structure of the steel, as affected by heat treatment and chemical composition, and as revealed by polishing, etching with acid and examining with a microscope; and

b A study of the critical temperatures just referred to, and the very evident connection of these critical points with the powerful internal changes in the quality, condition or formation of the carbon which causes the tool to be hard in one case and soft in another.

1108 A clear understanding of the effect of these critical points in hardening is helped by diagrams showing them graphically.

1109 If paper be ruled with horizontal lines at equal distances art which represent increases in temperature, say of 100 degrees each, l if upon paper ruled in this manner a line be drawn consisting of a ies of dots which are spaced at distances one from another, corre-onding to the rapidity with which the temperature of the steel falls it is cooled; when the critical points in the cooling are reached, the ling curve will be bent sharply either to the right or to the left, ning a very definite and clearly visible break or sharp deflection m the general line of the curve, and in this way the exact location of remarkable changes in the carbon of the steel from hardening to ening carbon, etc., becomes clearly visible at a glance.

1110 In the diagram, Folder 10, Fig. 56, is shown a set of these ves which represent the critical points in cooling and heating steel the chemical composition of ordinary carbon or tempering tool el, and in the diagrams, Folder 10, Figs. 57 and 58, are shown cool-; and heating diagrams of the modern high speed tools. Fig. 56 s sent to the writer through the kindness of Prof. H. C. H. Car-ter, and Figs. 57 and 58 are reproduced from Professor Carpenter's per above referred to. These diagrams represent the best work this character which has as yet come to the attention of the writer.

1111 On Folder 10, Fig. 57 (Alloy 14), and Folder 10, Fig. 58 (Alloy 6), is represented the cooling of two different modern high speed tool eels of the following chemical compositions respectively:

FIG. 57

Carbon	0.85 per cent
Chromium	3.0 per cent
Tungsten	12.5 per cent

FIG. 58

Carbon	0.55 per cent
Chromium	3.5 per cent
Tungsten	13.5 per cent

1112 The curves on the left-hand side of the vertical line represent the cooling curves, those on the right-hand side represent the heating curves. The five curves on the left-hand side represent the cooling of the steel after it has been heated to 1652 degrees Fahr. (900 degrees C.), 1832 degrees Fahr. (1000 degrees C.), 2012 degrees Fahr. (1100 degrees C.) and 2192 degrees Fahr. (1200 degrees C.), respectively, and in all of these curves sharp bends to the right which begin to occur at from about 1364 degrees Fahr. (740 degrees C.) to 1324 degrees

Fahr. (718 degrees C.), indicate very clearly the critical points at which some powerful molecular change occurred during the process of cooling.

1113 Mr. White and the writer, during the orginal development of modern high speed tools by us, accurately heated chromium-tungsten tools of standard shapes, one set after another, to different temperatures, and then determined their standard cutting speeds, as described in paragraphs 106 to 109. This accurate practical heating and running of the tools (without any theory on our part as to the chemical or molecular causes which produced the extraordinary phenomena) led to the discovery that marked improvements in the cutting speed of chromium-tungsten steel were attained by heating the tools from a temperature of 1725 degrees Fahr. (958 degrees C.) up close to the melting point; the higher the point to which the tools were heated, the greater was the cutting speed attained.

1114 By referring to the several curves, it will be noted that in the 1652 degrees Fahr. (900 degrees C.) curve (on the extreme left of the diagram) which is below the point (1725 degrees Fahr.) at which high heating begins to make large improvements in the cutting speed, there is much greater deflection or internal chemical change when the critical point is reached in cooling the tool than in the curves of those tools which were heated to the higher temperatures, and that particularly in the diagram (Alloy 16), Folder 10, Fig. 58, the higher the tool is heated, the smaller becomes the sharp bending of the curve to the right, and therefore the smaller becomes the molecular action or change in cooling down the tool at the 1332 degrees Fahr. (722 degrees C.) critical point.

1115 It would seem logical, therefore, to infer that there is some connection between the increase in the cutting speeds of these tools as they are heated higher and higher, and the diminution in the molecular action at the 1364 degrees Fahr. (740 degrees C.) and 1324 degrees Fahr. (718 degrees C.) critical points. Yet it must be remembered that "high speed" tools possess the two distinct properties of "hardness" and "red hardness" and that the high heating (in the case of chromium-tungsten tools) progressively improves both of these qualities; therefore our experiments and observations have led us to the conclusion that these heating and cooling diagrams are valuable chiefly in their relation to the quality of "hardness," not in their relation to "red hardness." Our reasons for this will be given later in paragraphs 1119 to 1123.

1116 Curves or diagrams of the type shown in Figs. 57 and 58, however, throw no light upon the important question as to the exact

at which the tempering or softening of the high speed tool begins, to what range of temperatures this softening process extends. writing his interesting paper, above referred to, Professor nter made another investigation, the results of which were shed under the title of "Tempering and Cutting of High l Steels" in the "Journal of the Iron and Steel Institute," 1906, for the purpose of determining the range of the tempera- at which tempering or softening of high speed tools begins, he range of temperatures through which softening extends and is y completed. In this investigation he used the first method of tific investigation above referred to in paragraph 1107 (A); ly, an examination of the microscopic structure of the steel. 'older 4, we reproduce one of his plates illustrating the typical ture of high speed steels proceeding from its hardest to its softest , and we quote Professor Carpenter's discussion[1] of these plates, ng extracts from pages 4 and 5 of his paper:

7 "Characteristic structures of the hardened and fully tempered tened alloys are shown on Folder 4, Figs. 19a and 19e. Fig. onsists of white polyhedral crystals, and Fig. 19e of small white als embedded in a darkly etching matrix. The difference een the two types of structure is very characteristic, and the pro- of tempering can be followed readily by microscopic examination.

No tempering occurs below 550 degrees C. At this tempera- the structure seen on Figs. 19b and 19c is obtained. The white represent untempered material, the colored areas parts where ering has begun. Tempering starts from a series of centers, gradually invades the rest of the material. Photomicrograph, er 4, Fig. 19c, shows that the incipiently tempered material con- of a mixture of lightly colored polyhedra, needles, and a darkly ed matrix. At 600 degrees C. the white polyhedra disappear, the structure consists of a fairly uniformly colored, ill-defined ular mass from which all evidence of polyhedra is absent. The patches probably represent the centers from which tempering eeded (see Folder 4, Fig. 19d). At 650 degrees small white crys- make their appearance, but they do not attain their proper pro- ion, corresponding to fully tempered material, until after treat- t at 700 degrees C. Thus in the case of this alloy tempering was cturally detected at 550 degrees under the conditions of experi- t chosen, but was not complete till 700 degrees."

[1] In this quotation we use of course our own folder and figure numbers in the of those used by Professor Carpenter.

1118 In reading the above quotation it should be borne in min Professor Carpenter used the word "tempering" in the sense of pr sive softening, or what is commonly called by blacksmiths in th of ordinary carbon tools "drawing the temper."

1119 Professor Carpenter made elaborate tempering or sof experiments at accurate temperatures upon nine different some of which represented the best modern high speed tools a time available, while others represented steels more or less ap mating to the best high speed tools. In the course of this inv tion it appeared that one of these alloys of the following ch composition required to soften it materially higher temperature any of the others.

	Dr. Mathews' Steel. No. 8	No. 8
Carbon	0.47	0.43
Silicon	0.15	0.04
Sulphur	low	0.01
Phosphorus	low	0.02
Manganese	0.1 to 0.2	0.17
Chromium	2.99	3.10
Molybdenum	4.29	4.17

The etched specimens examined with the microscope showed th alloy began to distinctly soften at a higher temperature than any others, and was not completely softened even at 930 degrees C., wh others were completely softened at about 700 degrees C. In vi this very high softening point for this particular steel, Professo penter had cutting tools made from steel very closely resembling of the analysis shown in column No. 8b, and these tools were competition with high speed tools in general similar in composit the following:

Carbon	0.55 per ce
Chromium	3.5 per ce
Tungsten	13.5 per ce

1120 The result of these practical speed tests with tools sh that the steel which resisted tempering or softening at the high of 800 to 930 degrees C. was far inferior in cutting properties to th speed steel which was completely softened at about 700 degrees

1121 This experiment, which was very thoroughly condu shows conclusively that this second scientific method of investig fails in attempting to establish any practical relation between th

ing properties of high speed tools and their microscopic structure and his conclusion agrees exactly with that arrived at by Mr. White and the writer in our original investigation in developing the high peed tool. We found, as stated in our patent, that many high speed ools contain austenite, a structure only to be produced by excessively igh heats and indicative of great hardness. We also found in our nicroscopic examination other structures somewhat similar to those llustrated by Professor Carpenter. Although our examination in his direction was far from being as thorough as that of Professor Carpenter, we went far enough to completely satisfy ourselves that here was no traceable relation between the highest cutting speeds and ny particular one of the microscopic structures. We examined sev-ral high speed tools which showed equal cutting properties and yet hose microscopic structure differed very materially

1122 Professor Carpenter has traced the relation between these nicroscopic structures and the "hardness" of the tools, and we have o doubt that in this investigation,—as well as in his former investi-ation showing the relation between the cooling curves and the "hard-ess" of the steel,—that he is correct; but like all the other scientific riters on this subject whose works have come to our attention, he has iled to recognize the existence of "red hardness" as a property of ese steels entirely independent of hardness. We would again call ttention to the fact that the highest degree of "red hardness" can be ound in these high speed tools when accompanied either by the ighest degree of *hardness*, on the one hand, or by a very *considerable* egree of *softness*, on the other hand. And we repeat most emphat-ally that hardness in high speed tools is in no sense a guide to their igh speed qualities which depend mainly upon the quality of red ardness. As illustrating this fact, we refer again to the photograph, older 3, Fig. 18, which shows a high speed tool with deep nicks hich were readily filed in it with an ordinary carbon steel file after it had n successfully at high speed. It is also a fact that the No. 1 tool, older 20, Table 138, which when properly treated represents the best l-round modern high speed tool for cutting metals of all qualities perimented with is not a particularly hard tool. It is less hard, for ample, than the old fashioned Mushet tools, and far less hard than most all of the high speed tools alloyed with molybdenum. It can e filed with a hard carbon steel file, and yet, in spite of being only oderately hard, it possesses the very highest degree of red hard-ss.

1123 We would also call attention to the fact that in Profesor Car-nter's description of the photographs of the steel structures illus-

trated on Folder 4, he states that softening has proceeded so far at the temperature of 1022 degrees Fahr. as to change the hard structure shown in Fig. 19a to the distinctly softer structure shown in Fig. 19c. It will be remembered that paragraphs 991 to 993 state that the very best high speed tools were produced by reheating the tool to a temperature of 1150 degrees Fahr. This was done for the purpose of imparting the very highest degree of red hardness to the tool. It is clear, then, that if softening has progressed, as shown in Professor Carpenter's paper, very materially at a temperature of 1022 degrees Fahr. and if, on the other hand, the highest degree of red hardness is imparted to the tool by reheating it to at least 1150 degrees Fahr., there is not only a great difference between the qualities of "hardness" and "red hardness," but also that these two qualities are not affected at the same temperatures.

1124 Before accepting a theory in any particular case, the facts should be thoroughly established and verified, and the theory if correct should thoroughly account for all of the known facts.

1125 It is clear that as to high speed cutting tools the most important facts are best established by carefully heating the tools to known temperatures and then running them in standard speed tests under uniform conditions in cutting uniform metals, as described in paragraphs 137 to 148. This method of determining the qualities of cutting tools may be briefly called the method of "heating and running" the tools; and this, as already explained, was the method originally adopted by us in developing the high speed tools for arriving at all of the important facts then developed. Of these facts the most important are:

a how to produce tools having the greatest red hardness, that is, tools which will run at the highest standard cutting speeds on different qualities of metal; and

b the determination of at what temperatures and in what manner the quality of red hardness in the high speed tools is impaired or broken down.

1126 As we have already stated in our description of the experiments tried by us during the summer and fall of 1906, it is an extraordinary fact that the heat treatment originally developed by us through this method of "heating and running" the tool still continues to produce a greater amount of red hardness and higher cutting speed than any heat treatment since devised. We have not, however, since the original development of high speed tools in 1898 investigated by the method of "heating and running" the second important fact namely, at what temperature the quality of red hardness in the highe

mium and tungsten tools begins to be impaired. It may be that
best recently developed high speed tools will hold their quality
ed hardness at higher heats than those determined by us, and it is
great importance that this subject should again be thoroughly
stigated by the sure, though slow and expensive, method of heat-
and running.

127 Our original investigations showed that red hardness was
aired by heating tools above 1200 degrees Fahr., and that the
lity of red hardness was entirely removed by heating them up to
0 degrees Fahr. and holding at that temperature for any length of
e. Now, it will be noted that in the heating curves shown by Pro-
or Carpenter, no critical point is shown at these temperatures,
ich are the critical temperatures so far as we know for high speed
els and therefore the critical temperatures affecting red hardness.
fessor Carpenter's recent microscopic investigations on the struc-
e of steels and the temperatures affecting this structure show
ical structural changes beginning at below 1022 degrees Fahr.,
l extending up to 1292 degrees Fahr. It will be noted that the
ge of temperatures corresponding to these structural changes
h which Professor Carpenter has connected the quality of hard-
s in steels differs entirely from the range of temperatures which
found were intimately connected with the destruction or deteriora-
n of red hardness. Now, the temperatures which impair red hard-
ss in the latest high speed tool steels are without doubt as high or
en higher than those which impaired red hardness in our original
ols. All of these facts indicate clearly that the two methods as
t devised by scientists for determining the most important quality
the new high speed steels are ineffective.

And when we consider all of the facts, it is a matter of doubt whe-
her in producing the quality of "red hardness" in tools, carbon plays
he all-important part that it does in the quality of hardness. It
ay be questioned whether red hardness is not more intimately con-
ected with chromium, tungsten and molybdenum in their heat treat-
ment than with carbon.

1128 We do not wish to discourage the type of investigation
ndertaken by Professor Carpenter and Messrs. Osmond and LeChat-
lier. On the contrary, we believe it of very great importance to
find, if possible, some simpler index or guide than is now known, to the
utting properties of high speed tools, namely, some guide or index
hat is simpler than making elaborate standard cutting speed tests
ith carefully standardized tools upon standardized forgings. This
est requires so much expensive apparatus, consumes so much time,

and is so slow, that a simpler index or guide which will indicate correctly the quality of high speed tools is much needed. Moreover, we firmly believe that in time some simpler index to the property of "red hardness" in tools will be found.

QUALITY OF METAL BEING CUT

THE EFFECT OF THE QUALITY OF THE METAL BEING CUT UPON CUTTING SPEED

1129 Although we have given a large amount of study and made great numbers of experiments upon the effect of the quality of the metal being cut upon the cutting speed, yet we have met with less success in reducing this subject to a scientific basis than in the case of any other of the elements affecting the cutting speed of tools. In the present state of the art, at least so far as our knowledge of it extends, it is impossible to predict with accuracy the exact hardness (or more properly speaking, the effect of the quality of the metal upon the cutting speed) of the various forgings and castings which are worked upon in a machine shop doing a large variety of work.

1130 However, while this element of the problem presents great difficulties, still in the various machine shops which we have systematized we have always sooner or later succeeded in training the man who with the slide rule directs the speed of the machines so that he is enabled to predict with a fair degree of accuracy the hardness of the great bulk of the materials which are machined in the shop. This involves not only a careful study of the general data which we have obtained on this subject, but also a long and detailed study of the average hardness of the particular set of forgings and castings which the shop deals with.

1131 We would emphasize the fact that this study can only be made and the very useful knowledge which it supplies can only be attained through a careful investigation of the hardness of the individual forgings and castings as they are from time to time found in the shops. Such an investigation frequently results in a temporary delay in turning out the work in hand, and while it takes place, is of inconvenience to the general running of the shop and is expensive both in time and money. However, the final results obtained from such careful study are of the greatest value, and assistance in increasing the output of the shop.

1132 In well-managed shops the collateral advantages which result from these experiments are also great. When the attention of the

superintendent of the shop is brought to the irregularity in the quality of the various forgings and castings which are machined, if he is a man of the proper caliber, he takes steps to see that his castings and forgings are purchased upon carefully written specifications so as to establish a greater degree of uniformity; and this generally results both in a better quality of forgings and castings and also in materials which can be machined at higher cutting speeds. On the other hand, the type of superintendent or foreman is very frequently met with who can see nothing but the difficulties of obtaining sufficiently accurate data to enable the slide rule man to properly do his work, and such men are generally so firmly convinced that no good can come of the whole scheme of attempting to lay out tasks for workmen, that the company having a superintendent of this type had better either use some other scheme of management than ours or get another superintendent.

SYSTEMATIC CLASSIFICATION OF STEEL FORGINGS AND CASTINGS ACCORDING TO THEIR CUTTING SPEEDS

1133 For practical use in the machine shop it is evident that the most important and logical method of classifying all forgings and castings which are to be machined is in accordance with their cutting speeds.

1134 The man who operates the slide rules and assigns the proper cutting speeds for the machines is interested only in the quality of the forgings as far as it affects their cutting speeds. We have, therefore, divided all metals into classes according to their cutting speeds, which vary from one another with the common ratio of 1.1, namely:

Class No. 1 corresponds to that metal which will give us the highest cutting speed which we are likely ever to use in a machine shop;

Class No. 2 represents a metal whose cutting speed is that of Class No. 1 divided by 1.1, or

$$\frac{\text{Cutting speed of Class 1}}{1.1}$$

and so on, the cutting speed of each class being connected with the one preceding it by the ratio of 1.1.

1135 It is of great importance to connect this numerical scale of hardness (which varies by the common rate of 1.1) directly and permanently with certain qualities of metal and with cutting tools of definitely known cutting properties. As a basis for accomplishing this we would state that Class No. 13 upon this scale corresponds to

a cutting speed of 60 feet per minute, for a standard cut of 20 minut duration when a high speed $\frac{7}{8}$ inch tool (see Folder 5, Fig. 24) of th chemical composition of tool No. 27 (Folder 21) is used, taking a dept of cut of $\frac{3}{16}$ inch and feed of $\frac{1}{16}$ inch.

1136 Our experiments indicate also that Class No. 13 represen a speed of 99 feet (in round numbers 100 feet) for the best high spee tool (Folder 20, Tool No. 1), running under the same conditions stated in paragraph 744.

1137 Using this data as a basis, our scale of "hardness classe for metals can be connected with other shapes of tools and other qua ities of tool steel, other depths of cut, and other thicknesses of fee by reference to the various tables and formulæ given throughout th paper.

1138 In using this classification it will be noted that the b modern high speed $\frac{7}{8}$ inch tool, if cutting metal belonging to Clas would have a cutting speed of 316 feet per minute with a standa $\frac{3}{16}$ inch depth of cut and $\frac{1}{16}$ inch feed; and such a metal as this wou be much softer than any steel which is cut in a machine shop.

1139 By referring to paragraphs 545 to 747, it will be seen th for what we call a hard steel forging of about the quality of a hard loc motive tire, a cutting speed of 45 feet corresponds to Class 21 while a soft steel having a cutting speed of 198 feet corresponds t Class $5\frac{1}{4}$.

1140 Having a clearly defined hardness classification of this so for metals enables us to tie all of our experimental and practical wo for years past together, even although tools of different chemic composition, and therefore of different cutting speeds, were use This system of classification is also admirably suited for use on a sli rule.

THE EFFECT OF THE QUALITY OR HARDNESS OF STEEL FORGIN UPON THE CUTTING SPEED

1141 There are three important elements which affect the hardn or the cutting properties of steel forgings:

a Their chemical composition.

b The thoroughness with which the metal is forged, that the amount that the cross-section of the ingot has be reduced in making the forging and the forging heat.

c The subsequent heat treatment which the forging receive that is, whether it has been laid down to cool in the ai annealed, or oil hardened, and the exact temperatures annealing and the rapidity of cooling.

1142 All of these three elements are so complicated that for men not engaged in the manufacture of steel there is but little use in attempting to consider them. It may be said, however, that for steel containing 0.40 per cent of carbon or less, the percentage of carbon is a fairly reliable guide to the hardness or cutting speed.

THE GUIDE TO HARDNESS AS IT AFFECTS CUTTING SPEEDS LIES IN THE PHYSICAL PROPERTIES OF STEEL AS INDICATED BY THE TENSILE STRENGTH AND PERCENTAGE OF STRETCH AND THE CONTRACTION OF AREA OF STANDARD TENSILE TEST BARS CUT FROM THE BODY OF THE FORGING

1143 The physical properties of steel constitute a fairly accurate guide to its cutting speed; and these properties are best indicated by the tensile strength and percentage of stretch and contraction of area obtained from standard tensile test bars cut from such a position in the body of the forging as to represent its average quality and then broken in a testing machine.

1144 It is of course impossible in most cases for any ordinary machine shop to cut test bars from the forgings which are actually used in the shop. It is, however, entirely possible and in many cases desirable to purchase forgings and castings with certain guaranteed tensile strength, stretch and contraction, and thus insure both the superior quality of the metal bought, and at the same time obtain metal practically uniform in its cutting speed. In our search for a guide to the cutting speed of metals, this has proven to be only reliable index to the cutting speed.

1145 On Folder 23, Table 141, and also on Folder 12, Tables 81 and 83, we record a large number of steel forgings which were accurately standardized by us in the course of our experiments. Their chemical composition and physical properties will be found opposite the cutting speeds for our standard $\frac{7}{8}$ inch tool, with standard 20-minute cut, $\frac{3}{16}$ inch depth of cut and $\frac{1}{16}$ inch feed, the speeds in the column corresponding to tool No. 27 (Folder 21) and in the other column to tool No. 1 (Folder 20).

1146 We have purposely given a large number of forgings, many of them of chemical composition and physical properties closely resembling one another, in order to show that no absolute and accurate relation exists between the cutting speeds of forgings whose chemical, and even physical, properties very closely agree. A study of this table, however, will show that in general the cutting

speeds grow slower as the percentage of carbon in the steel to be grows greater. In general, also, it will be noted that the cutt speed becomes slower as the tensile strength of the metal becon higher, and that the cutting speed grows faster as the percentage stretch increases.

1147 We have discussed at considerable length in paragraphs 5 to 579 (theory as to why pressure has no relation to cutting speed theory explaining why the cutting speed increases with an incre of stretch and diminishes with an increase of tensile strength. may be proper to add that there are two reasons for a falling off the percentage of stretch in steel forgings or castings; one of th being an increase in the hardness of the metal, and the other be an inferiority in the quality of the metal.

1148 Now a falling off in stretch due to increased hardness metal will cause a slower cutting speed in the tool, while a fall off in the percentage of stretch due to an inferior quality of me will not necessarily cause a slower cutting speed. For this rea the physical properties of steel are not an exact guide to cutting speed unless the quality of the metal is clearly known. *quality* we here mean whether it has been made of good mater well melted, forged, and has received proper subsequent h treatment.

1149 We have developed the following empirical formula wh is at least a partial guide to the cutting speed of steel of good qual when the physical properties of the forging are known as represent by a standard test bar 2 × ½ inch cut from the body of the fo ing and broken in a testing machine.

$$V = \frac{125\left(1-\frac{215}{(15+E)^2}\right)}{\sqrt{\frac{S}{10000}}-3-0.9}$$

In which V = Standard cutting speed;
S = Tensile strength in pounds per square inch;
E = Percentage of elongation of specimen 2″ x ½″.

1150 The cutting speed as represented by this formula will found in the column in Folder 23, Table 141, opposite the actual spe obtained from running the tools, and an inspection of the figu given in these two columns will indicate the degree of accura with which the formula represents the facts.

1151 It will be noted that in the very highest cutting spe

also in the slower cutting speeds no values are given in the for the formula. We omit these values because at both high and low extreme limits, the formula does not correspond to the facts. We do not, therefore, feel satisfied with this formula, and shall endeavor to find a substitute that is better.

1152 It is well known that in the harder grades of steel, particularly those which are harder than hard tire steel, both the tensile strength and the percentage of stretch are variable, that is, materially different results will be shown from test bars cut from the same forging. For this reason also the tensile strength and stretch, in our judgment, will never prove an accurate guide to the cutting speed of very hard forgings. However, it is the best guide at present known, and therefore has a certain value.

1153 We have tried experiments along several different lines in our endeavor to find some quick and reliable index to the hardness (i. e., the qualities which affect the cutting speed) of forgings and castings, all, however without satisfactory, practical results. Among these we would mention:

a the ordinary abrasive tests in which metals of known hardness are used to scratch the metal to be examined;

b indenting the metal which is to be cut by pressing a punch or knife edge with a given pressure down into the face of the metal to be tested, and then measuring the extent of the indentation.

c The use of a special drilling machine, in which standard drills are used under definite pressure, and in which the distance drilled in a given number of revolutions is measured.

1155 The best apparatus of this type has been gotten up by Mr. William J. Keep, of Detroit, Mich. This is useful for certain castings, particularly when they are produced in the same foundry and from mixtures which are in a general way similar from day to day. It is applicable, however, to a comparatively small range of work.

1156 One of the greatest needs in the art of cutting metals is a more accurate standard by which to foretell the cutting speed of forgings and castings, and this should form a subject for future experiments.

EFFECT OF THE QUALITY OR HARDNESS OF THE CAST IRON UPON THE CUTTING SPEED

1157 It is much more difficult to predict the correct cutting speed for cast iron than for steel, and as yet no reliable method for doing this has come to our attention.

1158 Viewed from the standpoint of chemical analysis, the cut ting speed becomes slower, the larger the amount of combined o cement carbon contained in the casting, and the cutting spee becomes less the smaller the amount of silicon contained in the cast ing. The amount of combined carbon, however, depends largel upon the rate or rapidity with which the cast iron has been coole after being poured into the mold; so that the mixture of the met in the cupola does not constitute an accurate guide to the hardne of castings.

1159 It is needless to call attention to the fact that thin se tions of cast iron which are cooled rapidly are harder and must b cut at slower cutting speeds than thick sections of metal mad from the same heat and cast at the same time. Therefore, a stud of the hardness of castings as it affects their cutting speeds must b made in each machine shop upon the particular castings actuall used in order to obtain reliable results.

THE QUALITY OF RED HARDNESS IN TOOLS PLAYS A MUCH SMALLE PART IN CUTTING CAST IRON THAN IN CUTTING STEEL THEREFORE, WITH HIGH SPEED TOOLS THERE IS A MUCH LESS PERCENTAGE OF GAIN IN CUTTING CAST IRON THAN IN CUTTING STEEL

1160 It is a constant source of surprise that the high speed to do not make the same proportionate gain in cutting cast iron as th do in cutting steel. Exact figures will be found in the table Folder 20, where by comparing the cutting speeds of tools No. (old fashioned carbon tempered tool) and No. 65 (old style Mus self-hardening tool) with the best high speed tool No. 1, it will noted that in cutting cast iron the best high speed tool cuts only ab three and one-third times as fast as the old fashioned carbon to while when cutting both very hard and medium steel, the new h speed tool cuts between six and seven times as fast as the carb tool.

1161 We have given in paragraph 523 a partial explanation these facts. A further explanation of this curious phenomen lies in the fact pointed out in paragraphs 964 to 966, that the mo important property, namely, that which gives the great improv ment in the high speed tools over the old fashioned tools, lies in t quality of red hardness which is possessed by these tools and whi does not exist in the old tools.

1162 It will be remembered that red hardness is the quali

ich enables a tool to withstand that portion of the wear which is ed principally by the heat produced through the pressure of chip on the tool.

163 Now, in cutting almost all qualities of cast iron, the wear the tool is due to two causes:

a the abrasive or grinding action of the carbon or gritty matter contained in the body of the iron itself; and

b the heat generated by the pressure of the chip upon the tool.

164 In resisting the second of these causes for injury to the ls (*b*) the quality of red hardness tends greatly to increase the ing speed. However, there is no doubt that the first of the o causes (*a*) plays much the more important part in injuring ls which are cutting cast iron, and in resisting this abrasive ion the quality of red hardness is of but little use. For the same son also, in cutting sand on the outside of castings or a mixture and and iron, the high speed tools are but little better than the d fashioned self-hardening tools.

TTING SPEED OF CASTINGS AS FOUND IN THE AVERAGE MACHINE SHOP

1165 As a broad general guide to the cutting speeds to be used r cast iron with the scale on the castings just as they come from e foundry, we would state that as the average of several machine ops in this country, it is our observation that medium cast iron ay be said to belong to Class No. 18 to 19 in our scale of hardness, nd that when cutting with a standard $\frac{7}{8}$ inch tool, of the quality f steel tool of No. 1, Folder 20, Table 138, with a standard 20-minute e, a $\frac{3}{16}$ inch depth of cut and $\frac{1}{16}$ inch feed, they have a cutting eed of 60 feet per minute. On the whole, what may be called e hardest castings frequently met with in machine shops are not rder than Class No. 24, giving a standard cutting speed as mentioned ve of 35 feet per minute. While softer castings quite frequently et with are as soft as class No. 11, and have a standard cutting eed of 120 feet per minute.

FECT OF SCALE ON CAST IRON CASTINGS UPON THE CUTTING SPEED

1166 As to the effect of the average scale met with in castings in average shop, our experience indicates that with very soft cast- the average scale met with calls for a cutting speed only about half as fast as the cutting speed of the same casting below the

scale, and that as the castings grow harder and harder, the cutti speed of the scale approaches that of the cast iron below the sca so that with the castings referred to just above as "hard" castin the cutting speed of the scale and of the metal below the scale about the same. On the medium castings referred to, the cutti speed of the scale may be said to be, in general, about three-fourt as fast as the cutting speed below the metal of the scale.

1167 In pars. 1163 and 1167 we refer to the effect of sa or a mixture of sand and iron upon the cutting speed of tools. addition to this, however, we would state that when castings a made containing a mixture of sand and iron, far more work can done by taking very coarse feeds, and we suggest as the standa remedy in machine shop practice, when these conditions are m with, the taking of a cut sufficiently deep to get well under t scale and then the use of as coarse a feed as practicable.

1168 It is obvious that in many cases, owing to the light sectio of metal being cut or owing to lack of pulling power in the machi it is impossible to take very coarse feeds or very deep cuts. It l no means follows that when these coarser feeds are taken, an excee ingly slow cutting speed must be used. In many cases the coa feeds when cutting mixtures of sand and iron can be accompani by fairly high cutting speeds.

LINE OR CURVE OF CUTTING EDGE

EFFECT OF LINE OR CURVE OF THE CUTTING EDGE ON THE CUTTI SPEED

1169 In paragraphs 278 to 315 we have pointed out the eff which the curve or outline of the cutting edge has upon the cutt speed, and we have endeavored to make it clear that the curve of t cutting edge of the tool affects the cutting speed chiefly because the variation in the thickness of the chip or shaving which it produc In general, the larger the radius of curvature of the cutting edge a the more nearly the general curve of the cutting edge lies parallel a general way to the center line, or axis, of the work which is bei cut, the thinner becomes the shaving and the higher the cutting spee

TOOL WITH CUTTING EDGE HAVING A CURVED OUTLINE PRODUCES CHIP VARYING IN THICKNESS AT ALL POINTS

1170 We have also, in these paragraphs, endeavored to make clear:

1) That a cutting edge, with a curved outline, invariably pro-
es a shaving which varies in its thickness at all points.

171 In Folder 16, Figs. 112 and 111, and in Folder 17, Fig. 120, larged views of our standard ½ inch to 1¼ inch tools) are given (on ale enlarged, in one case, sixteen times the full size of the tool, and the other case eight times the size of the tool) views of the actual ions of the chip as removed by tools having different shaped cut-g edges. By refering particularly to Folder 17, Fig. 120 (enlarged w of ½ to 1¼ inch tool) in the case, for instance, of a cut ⅛ inch in pth, the large difference in the shaving which is produced in one e by our ½ inch standard tool, and in the other case by our 1¼ inch l, will be clearly seen.

AGE CURVE FOR CUTTING EDGE. THINNING DOWN THE SHAVING PRODUCES FASTER CUTTING SPEED

1172 By referring to our Practical Tables (Folder 24, Figs. 143 nd 148) for cutting steel, using ⅛ inch depth of cut and $\frac{1}{16}$ inch ed, in the one case, with our standard 1¼ inch tool, and in the other se, with our standard ½ inch tool, the difference in the cutting ed produced by the thinning down of the shaving, owing to the ange in the curve, will be observed. The thinner shaving accom-panying the 1¼ inch tool in cutting medium steel, for instance, gives a cutting speed of 112 feet per minute as against a cutting speed of 1 feet for the thicker shaving of the ½ inch tool.

1173 It is obvious that some general law must exist for determin-e the relative cutting speed of tools having different curves for the outline of their cutting edges and that we should be able to determine is law by plotting on an enlarged scale the exact shape of the two ections of shavings which are being removed, as has been done in Folder 16, Fig. 112, and Folder 17, Fig. 120, and then comparing these hapes with their corresponding cutting speeds. We have once or twice started on this line of investigation, but have never had the ime, or as yet sufficient data to enable us to determine accurately his law, and this would seem to form an important subject for future nvestigation.

HE CUTTING SPEEDS OF OUR STANDARD TOOLS OF DIFFERENT SIZES COMPARED WHEN USING THE SAME DEPTH OF CUT AND FEED

1174 A comparison of the cutting speeds given in the Practical ables (Folder 24), with the cross-sections of the chips shown in lder 17, Fig. 120, will indicate the effect on the cutting speed of

the various sections of shavings produced by different depths of and thicknesses of feed when using our several standard shape tools, varying from $\frac{1}{2}$ inch up to $1\frac{1}{4}$ inch. In addition to obtair this information we have at various times made experiments to termine the relative cutting speeds of shop tools which are in o nary use and which differ very radically in the curve of their cut edges. The time when it is necessary to publish this paper is so c at hand that the writer is unable to give the full data connected v these various experiments. At a matter of interest, however, record the following general results of this work.

EXPERIMENTS UPON THE CUTTING SPEEDS OF PARTING TOOLS THREAD TOOLS

1175 Two sets of these experiments are of especial interest. set was made during the year 1888 in the works of the Midvale S Co. upon a large steel locomotive tire, and the other in 1903 at works of the Link-Belt Engineering Co., of Philadelphia, upon very thick rim of a cast iron fly wheel. It so happened that the r who were experimenting upon the cast iron fly wheel did not knov the experiments previously made upon the steel tire, and as the res of these two sets of experiments agree within from 3 per cent to 4 cent, the probability of their being reliable is all the greater. Th experiments were undertaken to determine accurately the relat cutting speeds for a parting tool and a thread tool when compa with our standard $\frac{1}{4}$ inch round nosed tool, and also with a tool hav a straight line cutting edge, cutting a shaving of uniform thickr throughout.

1176 By a "parting tool" we mean a narrow, square nosed t which is fed directly "end on" into the work for the purpose cutting it or slicing it into two pieces. The two corners of the part tools experimented with were rounded to the extent of about $\frac{1}{64}$ of inch.

1177 By a "thread tool" we mean the ordinary tool for cutt the United States Standard V Threads, having a 60 degree inclu angle. The extreme point of this thread tool was also squared to the extent of about $\frac{1}{64}$ of an inch.

1178 In cutting the steel tire, two different thicknesses of f were used, namely, 0.0156 inch and 0.203 inch; in cutting cast i also, two different feeds were used, namely, 0.0166 inch and 0. inch.

1179 In each case the standard cutting speed was found, for

ng tool, when it was only so badly injured that it could be economr reground by grinding away the clearance flank of the tool only. ch case the ratio of the cutting speed of the parting tool with n feed to that of a tool with a straight line cutting edge having h in length of the cutting edge under cut, and in which neither e extreme corners of the tool were cutting metal, was as 0.66 : 1 both tools were taking the same thickness of feed, that is, cut- chips of exactly the same thickness. The ratio of 0.66 : 1 was d to hold true when successively a thickness of chip of 0.0166 of 0.029 inch were used with both tools, and also when different ations of cut" were used with both shapes of tool. In one a duration of cut of 20 minutes was experimented with for both and in the other case a duration of 60 minutes was used.

180 The ratio of a thread tool to a tool with a straight line cut- edge under the same conditions, that is, when both were fed with ame feed, "end on," straight into the work, was as 0.45 : 1.

CTICAL RULE FOR FINDING PROPER CUTTING SPEED FOR A PARTING TOOL WHEN HIGH SPEED STEEL OF QUALITY OF TOOL NO. 1, FOLDER 20, IS USED

181 The practical problem, however, for the man who is running achine shop is to find quickly, when he has a given quality of tal, at just what speed he must run his parting tool or his thread to do the work with the greatest economy; and we would suggest following as a practical rule for obtaining the desired cutting ed.

182 Referring to our practical tables for cutting steel and cast on Folder 24. Find first the feed, *i. e.*, the thickness of the chip ch is to be cut by the parting tool; then look in the practical for cutting steel or cast iron as the may case be (Folder 24), for standard $\frac{1}{2}$ inch tool under $\frac{3}{16}$ inch depth of cut and with the thick- of the feed which corresponds most nearly to the given thickness e chip which is to be taken by the parting tool; read off the cut- speed from this table, and divide it by 2.7, and this will give the er cutting speed for the parting tool.

183 In other words, if we take the practical economical cutting d of our $\frac{1}{2}$ inch standard round nosed tool when using $\frac{3}{16}$ inch h of cut and a feed which is the same as the thickness of chip to t by the parting tool, the speed of our standard tool under these itions will be 2.7 times as fast as the proper speed for the parting

PRACTICAL RULE FOR FINDING PROPER CUTTING SPEED FOR A THREA TOOL WHEN HIGH SPEED STEEL OF THE QUALITY OF TOOL NO. 1, FOLDER 20, IS USED

1184 If in the same way we first determine the thickness of th chip over the point or extreme nose of the thread tool, *i. e.*, if we d termine the exact advance of the thread tool toward the center lin of the work each time a cut is taken, and call this advance the thick ness of the chip; and if we then proceed as described just above in th case of the parting tool, it will be necessary to divide the spee obtained for our standard round nosed tool by 4. Or, in other word if we take the practical economical cutting speed of our $\frac{1}{8}$ inch stan ard round nosed tool when using a $\frac{3}{16}$ inch depth of cut and a fe which is the same as the advance of the thread tool toward the cent line of the forging which is made after each cut taken by the thre tool, the speed of our standard tool under these conditions will be fo times as fast as the speed of the thread tool.

1185 More or less difficulty will be found in applying both of the rules, owing to the fact that in our practical tables (Folder 24) w have not given a large enough variety in the fine feeds. If time pe mitted we should give tables for the proper cutting speeds of thre tools and parting tools.

CUTTING SPEED OF BROAD NOSED TOOLS WITH STRAIGHT LINE CUTTIN EDGE COMPARED WITH STANDARD $\frac{1}{8}$ INCH ROUND NOSED TOOLS

1186 To show the relation in cutting speed existing between ou standard $\frac{1}{8}$ inch round nose tool and a tool having a straight line cu ting edge, cutting a shaving exactly one inch long, as shown i Folder 7, Fig. 35: If these two tools are set so as to take a depth o cut exactly $\frac{3}{16}$ inch, with a feed of 0.08 inch, then

$$\text{the cutting speed of our standard round nosed tool} : \text{the cutting speed of the straight edged tool} :: 17 : 24$$

In other words, if we know the cutting speed of our $\frac{1}{8}$ inch standar tool, and wish to find the corresponding cutting speed for a straigh edge tool having one inch of cutting edge under cut, multiply th cutting speed of our standard tool by 1.4.

1187 In paragraphs 312 to 314 we have referred to standar shapes for tools with broad cutting edges which we adopted and prac tically used for several years with excellent results. These broa

nosed tools are shown in Folder 7, Figs. 32, 33 and 34. When taking the same depth of cut and the same feed

$$\text{the cutting speed of our standard round nosed tool} : \text{the cutting speed of the straight edged tool} :: 17 : 22$$

Or, if we know the cutting speed of our standard $\frac{7}{8}$ inch tool, and wish to find the corresponding cutting speed of a broad nosed tool, multiply the cutting speed of the standard tool by 1.3. The relation between the cutting speeds of these types of tools was determined by us years ago with tools made of carbon tempered steel. They should again be accurately established through experiments with the best high speed tools.

SLIDE RULES

1188 Under the head of slide rules we refer to the practical solution of the mathematical problem which includes the laws as to the effect of the Twelve Variables referred to in paragraph 135 upon the three great questions:

WHAT DEPTH OF CUT SHALL BE USED?

WHAT FEED SHALL BE USED?

WHAT CUTTING SPEED SHALL BE USED?

1189 The practical and successful use of these laws as embodied in slide rules has been referred to by us in paragraphs 7 to 16, and in paragraphs 51 to 53 we have briefly described some of our efforts at solving this problem and the difficulties which we have met with. It may be of interest, however, to go somewhat more into detail upon this subject with a view to indicating in general the steps taken by us in its solution.

1190 Almost as soon as we had succeeded in developing formulæ which represented the results of our experiments, we realized the seriousness and difficulty of the problem before us in endeavoring to make practical and everyday use of these results. The first mathematical solution of the problem was made by Mr. G. M. Sinclair, who devoted, as the writer remembers, a year or more of consecutive work to this end with the help and advice of the writer.

1191 This solution was accomplished by means of overlying curves plotted on ordinary cross-section paper, with which we were able to work out laboriously and exceedingly slowly for each particular lathe or planer, a set of tables which could be used for most of the conditions met with in ordinary work. This method was, however, so exceedingly slow and laborious as to make it far from generally useful.

1192 After Mr. Sinclair left the problem, Mr. H. L. Gantt devoted a year or more of his time almost exclusively to its solution, and it was during this period that we substituted curves laid out on logarithmic paper for the direct curves laid out on ordinary cross-section paper. As a result of this work, we obtained a logarithmic sheet upon which both diagrams and figures were used to represent the laws and by means of an elaborate cross slide, upon which further elements of the laws were entered, we were able to make a more rapid and much more direct solution of the problem. This was done, however, by the method of trial and error, but by means of this crude sliding table we were able to make quite rapid approximations to the proper working conditions.

1193 It was not until after we began our experiments at the works of the Bethlehem Steel Company that we finally gave up the hope of obtaining a mathematical solution of this problem through the aid of some of the more noted mathematicians, as referred to in paragraphs 51 to 53. Mr. Gantt and the writer again attacked the mathematical side of the problem at Bethlehem, and substituted an especially made slide rule accompanied by diagrams, by means of which a still more rapid solution of the problem was obtained. When in this state Mr. Carl G. Barth joined our work, and together Mr. Barth, Mr. Gantt and the writer developed the final slide rule illustrated in Folder 11, Fig. 79, by means of which the problem is directly and very quickly solved. This slide rule has since been patented jointly by Messrs. Barth, Gantt and the writer. As before stated, however, Mr. Barth is a better mathematician than either Mr. Gantt or the writer, and it it very largely to his long continued work both on the slide rules and in revising the expressions for the laws that the present solution of the problem is due

1194 We had intended describing in detail the best method of procedure for incorporating the various laws given throughout the paper upon our latest type of slide rule, as indicated, in Folder 11, Fig. 79. The greater part of this paper, however, is already in print, and there remain but a few hours before the last section of the work must be in the hands of the printer. It is therefore with regret that this portion of the paper must be omitted. No mathematician, however, will have much difficulty in finding a comparatively easy method of incorporating those laws upon a slide rule.

1195 Attention is again called to the fact that all the mathematical formulæ representing the laws are suited for use on the slide rule. We have been limited to formulæ capable of logarithmic expression, and it is indeed fortunate that it has proved possible to represent

ly accurately with this single type of formula all of the laws ired to.

196 In Folder 11, Fig. 78, is illustrated a circular slide rule made Mr. Barth, which is used in connection with the lathe slide rule, g. 79, for quickly figuring the time required to do the work. Both ese slide rules are described by Mr. Barth in his paper, entitled e Rules for the Machine Shop as a Part of the Taylor System of agement," published in Volume 25 of the Transactions.

197 In paragraphs 113 to 119 the writer has indicated some of the ficulties attending the practical everyday use of these slide rules achine shops, and has also stated the fact that he has no very at hope of their rapid introduction into practical use. He would , however, that he looks upon task management as a matter of great moment, both to the workmen in raising their wages and ering strikes and labor troubles unnecessary and to the manu-turers in increasing and cheapening their output, that although he personally retired from the active introduction of this system of agement professionally, he is still devoting his time to furthering introduction of this system, and expects to make this the main ject of his remaining life's work. He wishes to state, therefore, he will be glad at all times to assist through advice any company ing to work along these lines.

DITIONAL EXPERIMENTS AND INVESTIGATIONS

198 A lack of time prevents the writer from summarizing under heading the various experiments and investigations which should undertaken in the future to acquire more knowledge in this art. have, however, from time to time throughout the paper suggested great need for further work, and the writer expects in the future prepare a short paper for the Society indicating what he believes be the more important lines for investigation.

FOLDER 1

PROCESS OF FORGING A STANDARD TOOL

FOLDER 2

VIEWS OF TOOLS IN PROCESS OF MAKING

FOLDER 3

VIEWS SHOWING WEAR ON TOOLS

RED HARDNESS

[redacted]

FOLDER 4

STRUCTURES OF TOOL STEEL

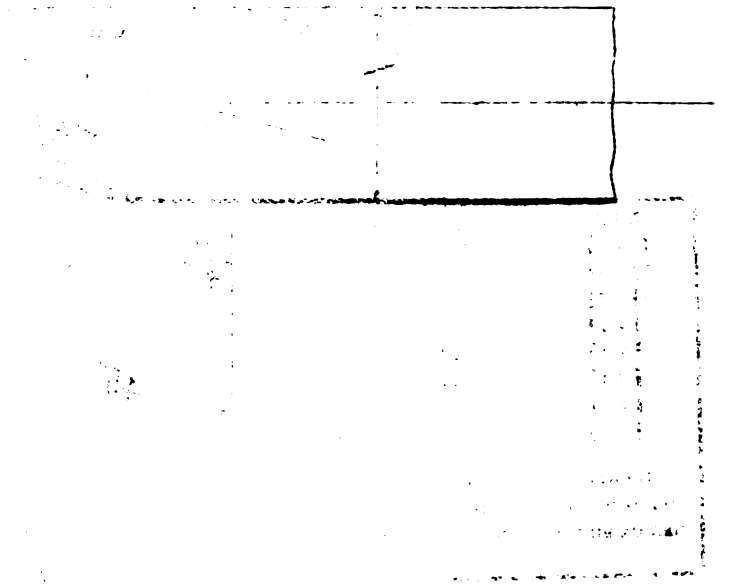
Photographs of Microscopic Sections

FOLDER 4

STRUCTURES OF TOOL STEEL

Photographs of Microscopic Sections

FOLDER 6



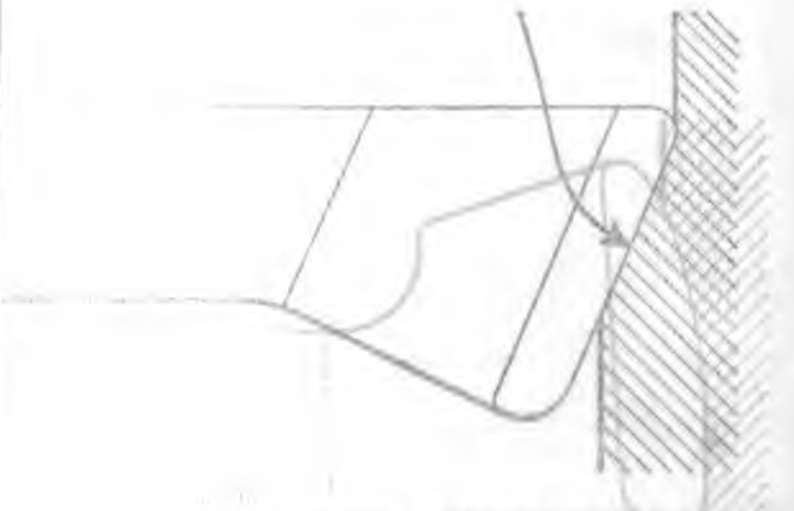
DEFINITIONS

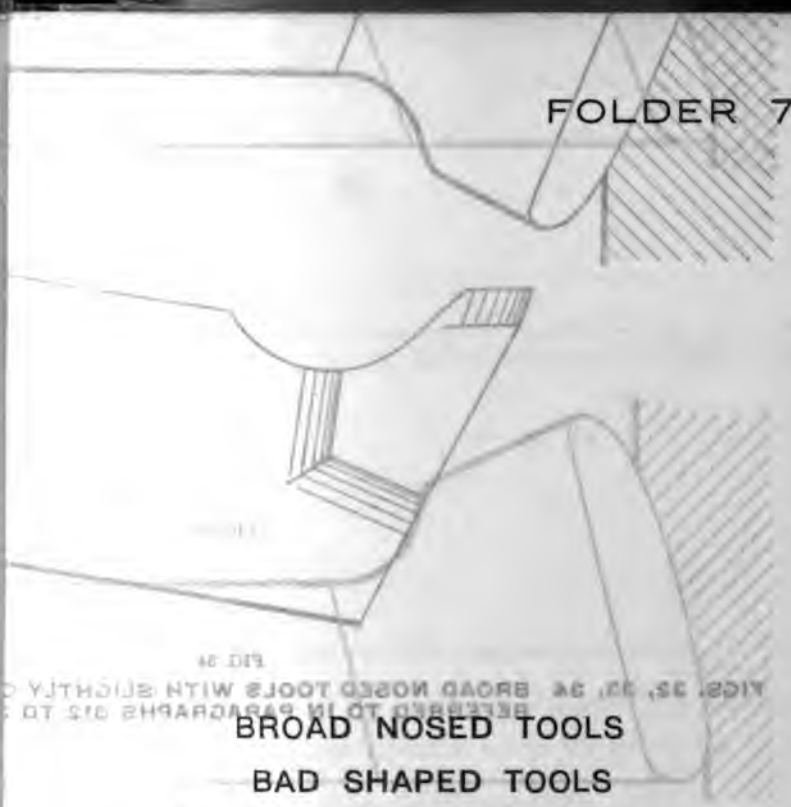
GAGE FOR FORGING TOOLS

BROAD NOSED TOOLS

BAD SHAPED TOOLS

COOLING TOOLS WITH WATER

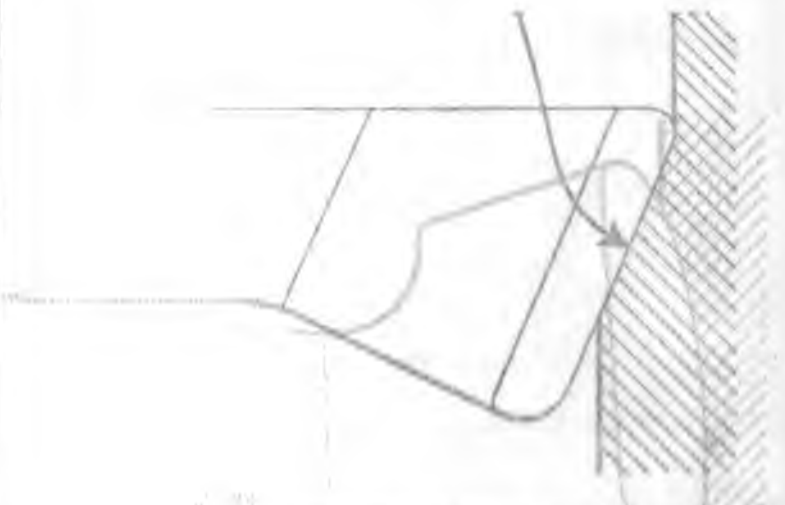




BROAD NOSED TOOLS

BAD SHAPED TOOLS

COOLING TOOLS WITH WATER



FOLDER 8

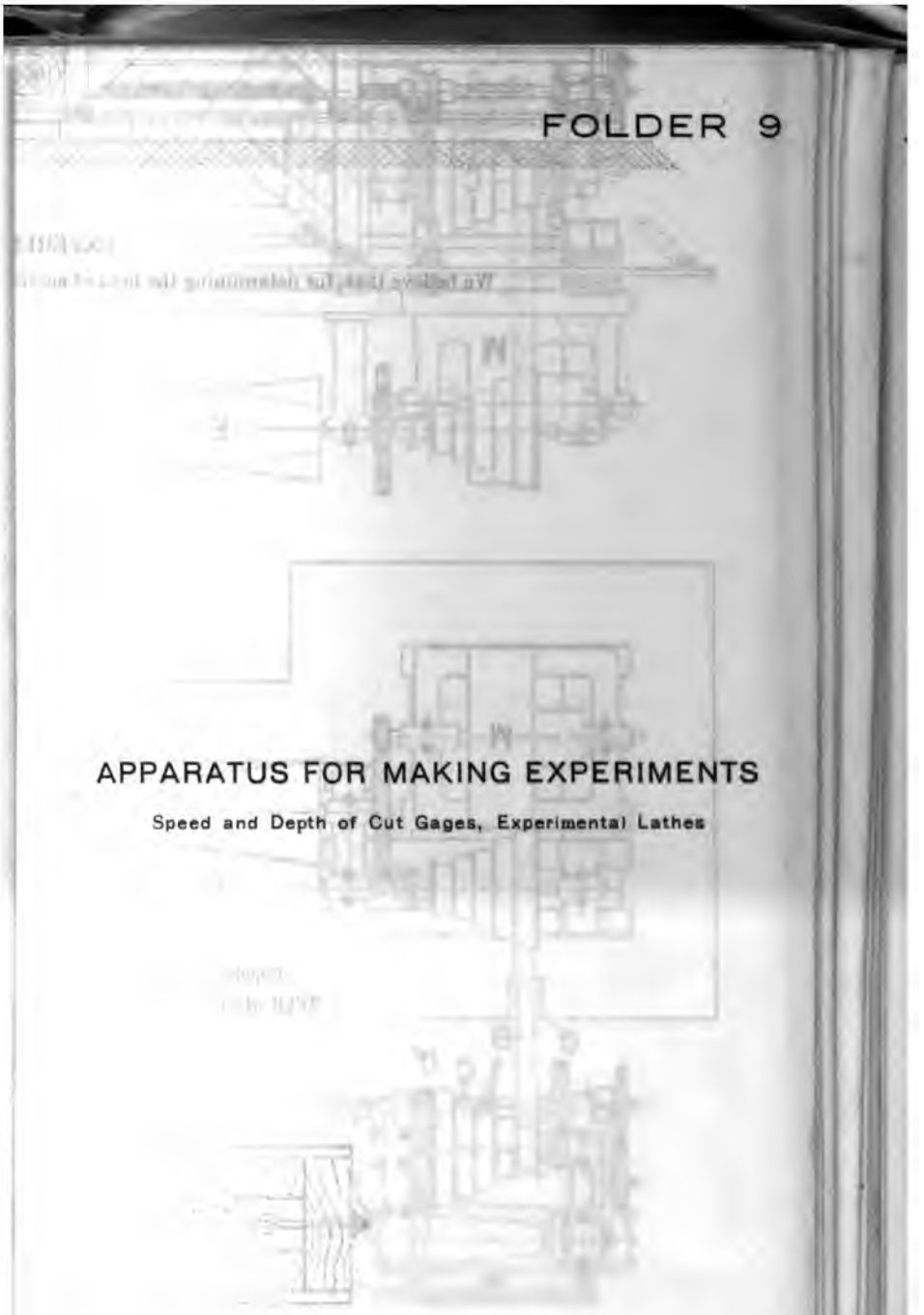
9

HOW CHIP IS CUT FROM FORGING

TABLE OF CUTTING SPEEDS

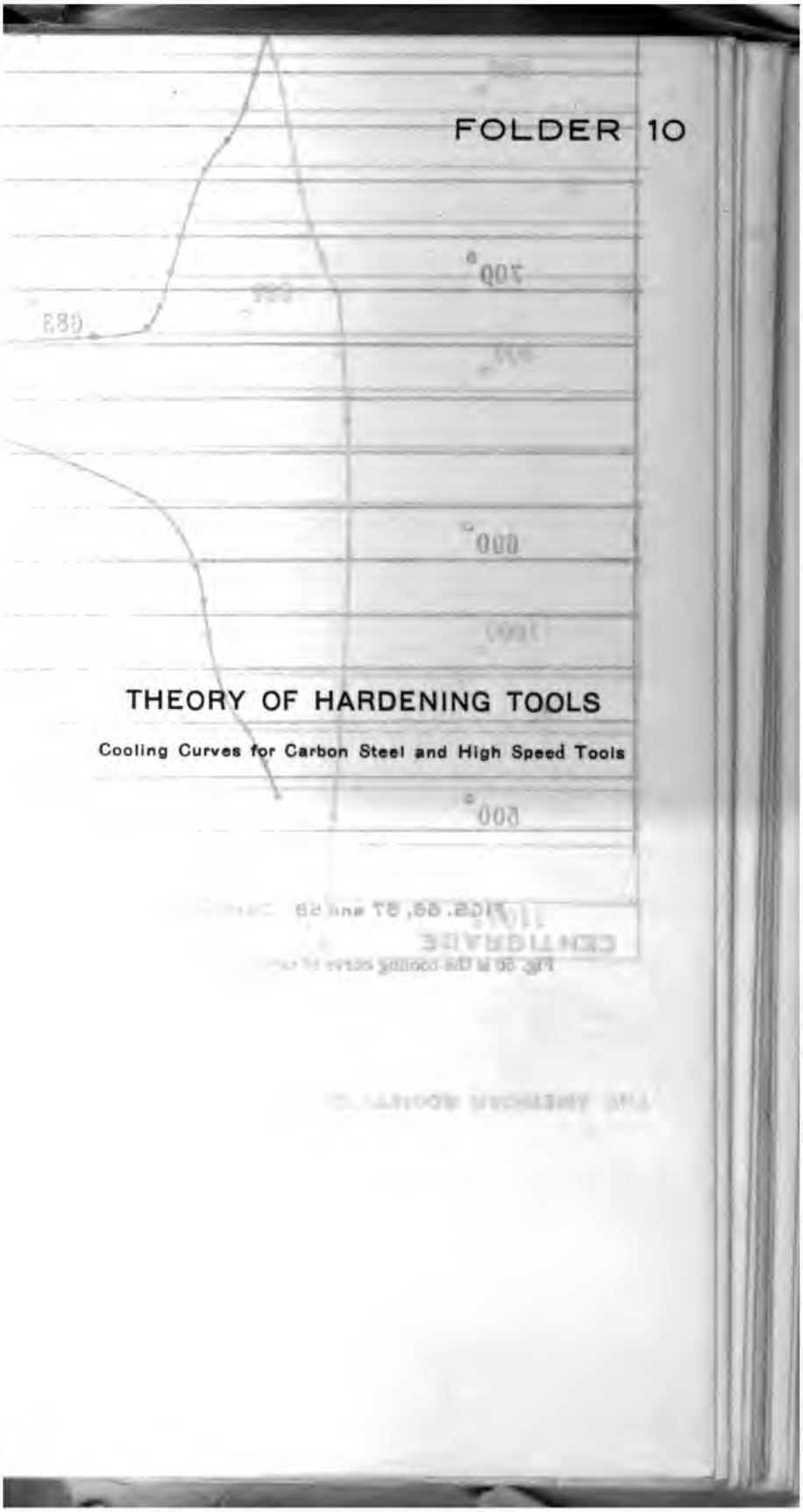
Sample of a Successful Series of Experiments

FOLDER 9



APPARATUS FOR MAKING EXPERIMENTS

Speed and Depth of Cut Gages, Experimental Lathes

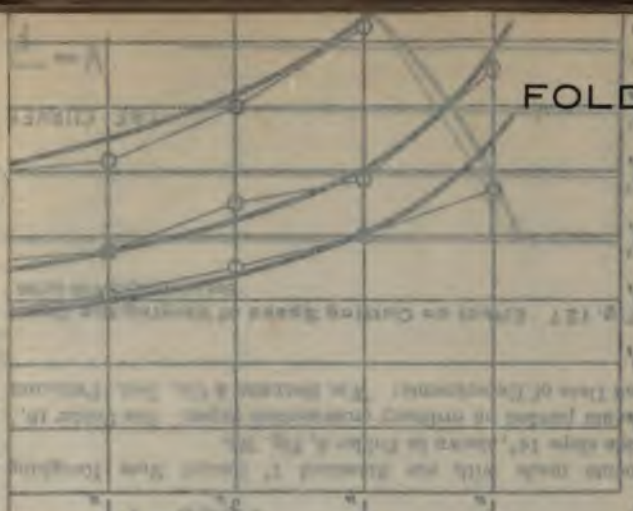


FOLDER 10

THEORY OF HARDENING TOOLS

Cooling Curves for Carbon Steel and High Speed Tools

FOLDER 18



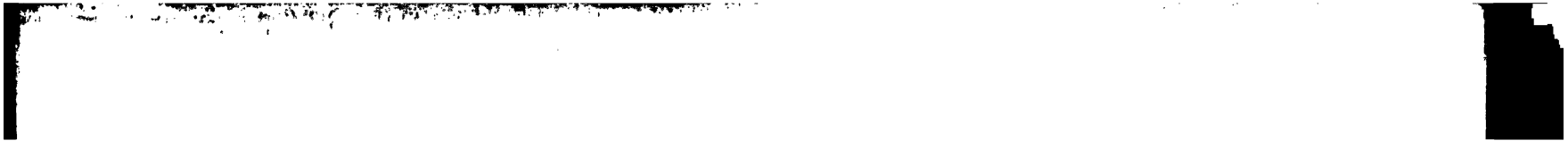
EFFECT FEED AND DEPTH OF CUT—STEEL

Effect of Feed and Depth of Cut on Cutting Speed in Cutting Steel

FOLDER 12

PRESSURE OF CHIP ON TOOL

Summary Tables of English, German and American Experiments

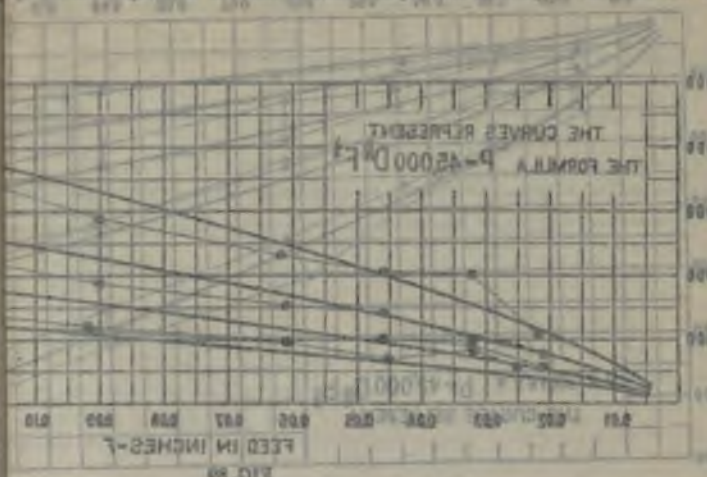


FOLDER 13

7

PRESSURE OF CHIP ON TOOL—CAST IRON

Tables and Diagrams giving Summary of our Experiments



FOLDER 14

PRESSURE OF CHIP ON TOOL-STEEL

Tables and Diagrams giving Summary of our Experiments

DURATION OF CUT

Effect of Duration of Cut on Cutting Speed, Practical Rule for Slowing Down Cutting Speed of Tool to make it last a long time without grinding

TIME TOOL LASTS BEFORE RE-GRINDING

WATER ON TOOL

FOLDER 16 17

THICKNESS OF THE SHAVING

Effect of Thickness of Shaving on Cutting Speed

CURVED LINE CUTTING EDGE

Effect of Curved Cutting Edge on Thickness of Shaving

FOLDER 17

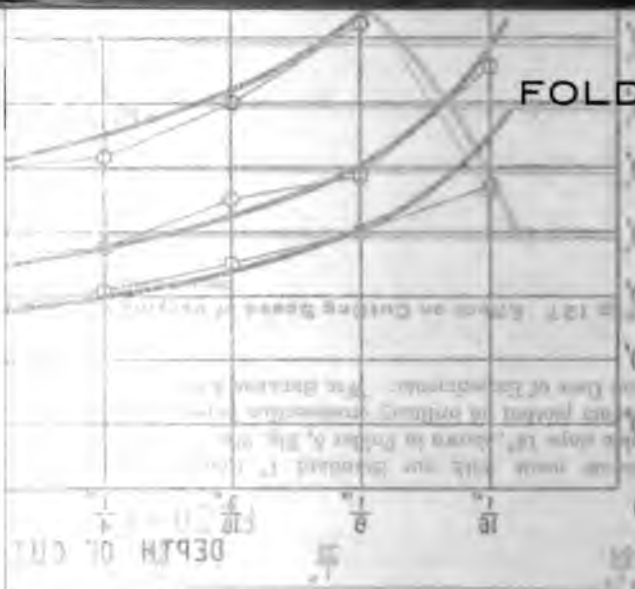
CURVED LINE CUTTING EDGE

Effect of Curved Cutting Edge on Thickness of Shaving

LENGTH OF SHAVING

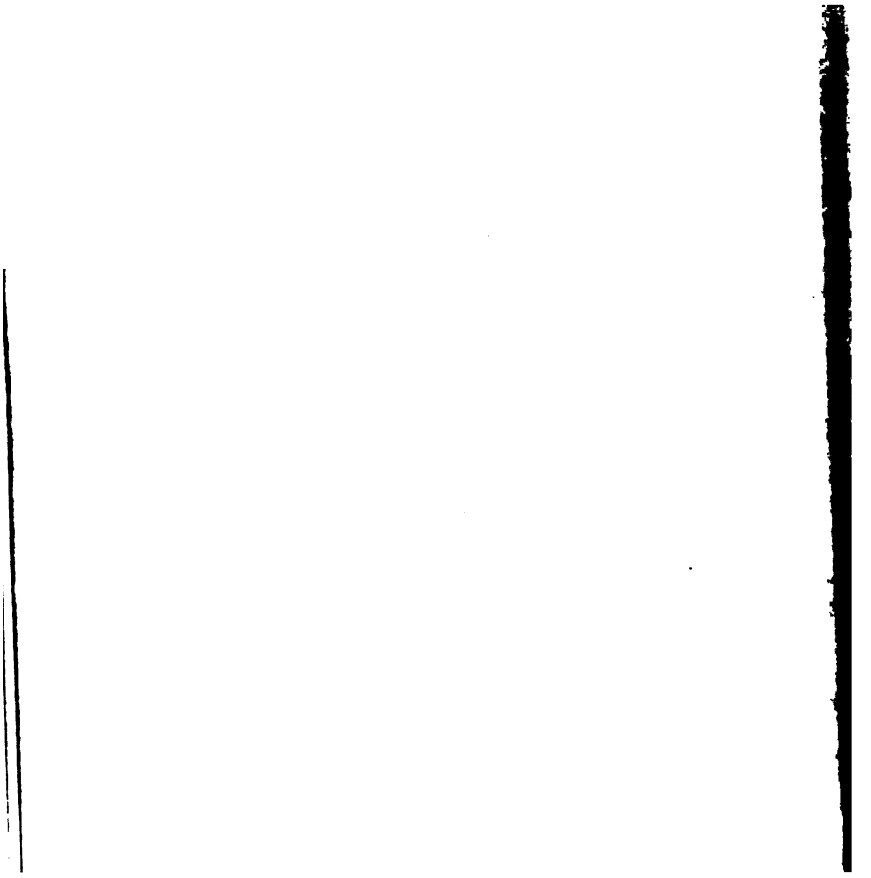
Effect of Length of Shaving on Cutting Speed

FOLDER 18

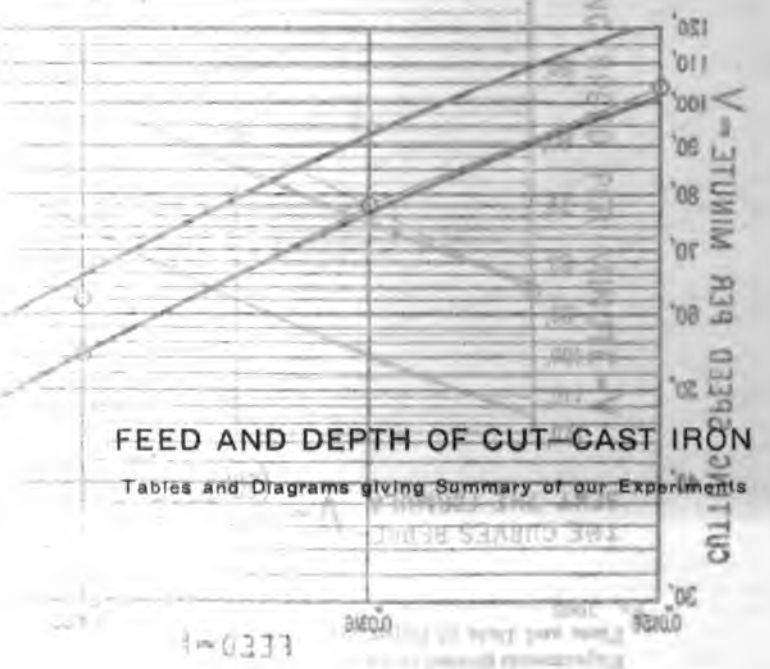


EFFECT FEED AND DEPTH OF CUT—STEEL

Effect of Feed and Depth of Cut on Cutting Speed in Cutting Steel



FOLDER 19



FEED AND DEPTH OF CUT—CAST IRON

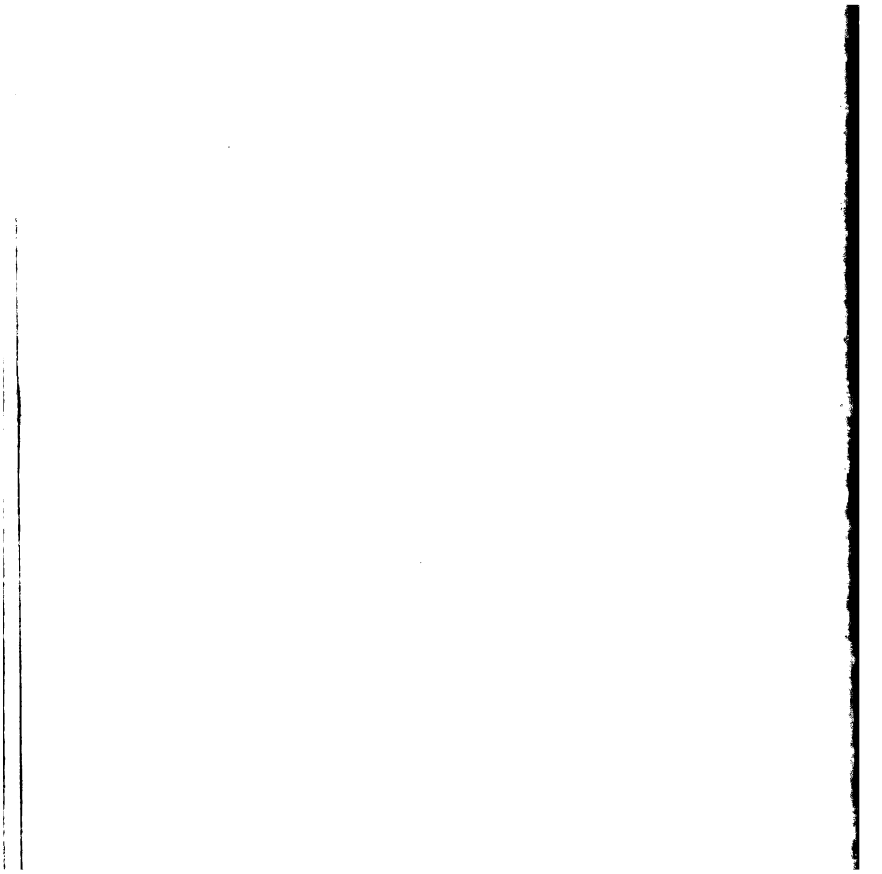
Tables and Diagrams giving Summary of our Experiments

FOLDER 20

TOOL STEELS

Analyses and Cutting Speeds of Best Modern High Speed Tools

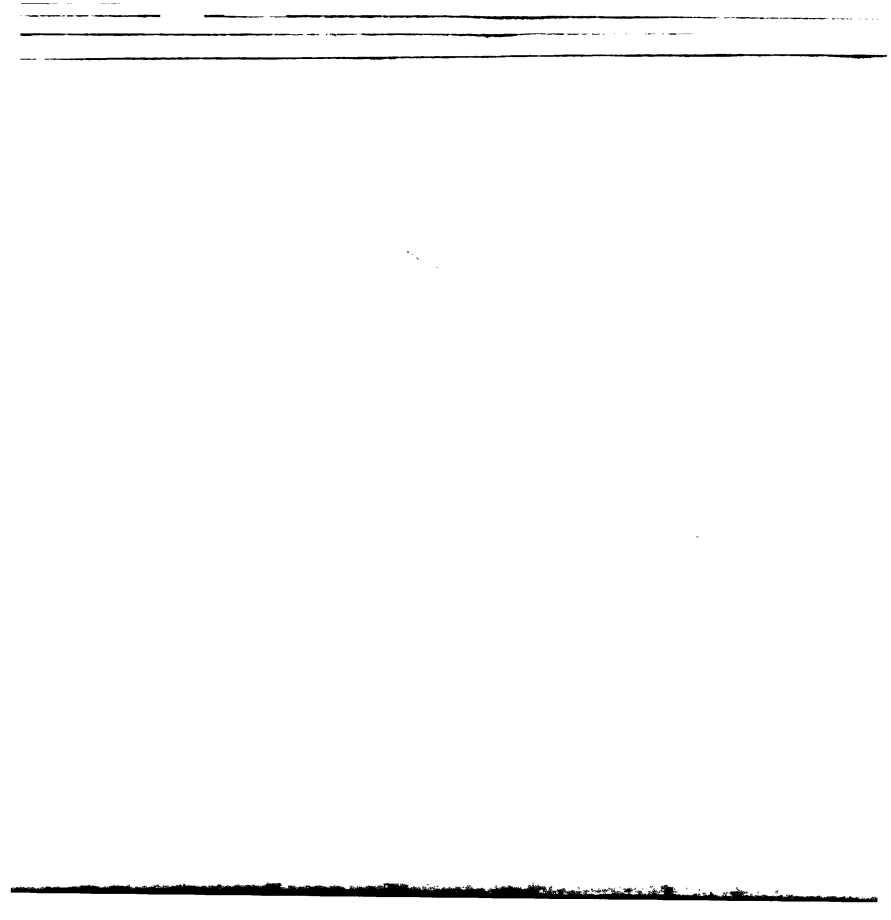
Analyses and Cutting Speeds of Typical Tools from Carbon Tools to Best High Speed Tools



FOLDER 21

TOOL STEELS

Analyses Showing the History of the Discovery and Development of Modern High Speed Tools



FOLDER 22

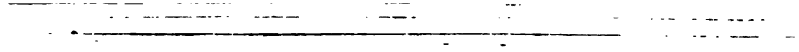
TOOL STEELS

Analyses of Carbon Tools and Old Fashioned Self-Hardening Tools

FOLDER 23

QUALITY OF THE METAL BEING CUT

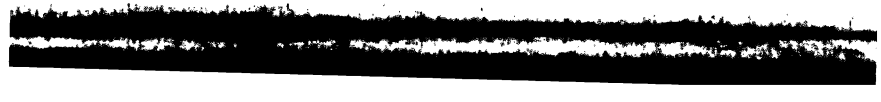
CUTTING SPEEDS 2 INCH SQUARE TOOLS



FOLDER 24

PRACTICAL TABLE OF SPEEDS

For Steel and Cast Iron with our Standard Tool of Various Sizes



DISCUSSION

ON THE ART OF CUTTING METALS

By F. W. Taylor, Published in November Proceedings

H. L. Gantt In our admiration of Mr. Taylor's paper as a
of scientific investigation, we are apt to overlook two things
to my mind, are of even more importance than the investiga-
self. They are:

a The object with which this investigation was undertaken;
b The far reaching results that have followed it.

Taylor emphasizes these points, but their importance cannot
restimated.

Briefly, this object was to set proper tasks for machinists with
e instructions as to the best way and the shortest time in which
form them.

The first results, and one soon obtained, was to find out that a
task in machine work set by a competent man after careful
igation was vastly greater than the task any man either would
ld set for himself based on the knowledge he had, or could get.
r investigations into other kinds of work indicated that this
as far reaching, and during 26 years of work under all kinds of
ions, not one exception has yet been found.

In day work and in ordinary piece work, unless the matter has
studied very carefully, the workman practically sets his own
which for day work is seldom more than one third of what he
have done, and often less than one fourth. His piece work
seldom over, and generally much less than one half of what can
ıe.

Under our task system of management, each piece of work is
lly studied, and such a task is set as can be accomplished only
good man fitted for the work. It is not expected that the ordi-
nan will succeed in doing it, at least not at first. The compen-
is set at a figure much above that usually obtainable by the
ry man, and almost always attracts the capable men.

essentials of a task are:

a What shall be done;
b How it shall be done;
c How long it may take.

6 Such a system is so radically different from the ordinary one in which at least one and frequently all three of these conditions are left to the judgment of the workman, that a man familiar only with the ordinary system of management finds it very difficult to adjust his ideas to the new methods. When, however, he has become accustomed to the new methods, he very seldom has any desire to return to the old ones.

7 Mr. Taylor's investigation of the laws of cutting metals is simply an illustration of how each of the innumerable questions that arise each day must be answered, not by somebody's opinion, but by an investigation that will determine the facts. These investigations are expensive and no company can afford to undertake many at one time, but it has been the writer's experience that the value of facts is so much greater than that of opinions, that properly conducted investigations seldom fail to give a handsome return on the money invested in them. I limit myself, however, to properly conducted investigations, for a great deal of money is wasted by people who do not know how to investigate. Most investigations undertaken by people not specially trained lead to negative results and a loss of the money spent. The writer, however, has never yet seen a properly conducted investigation that did not more than pay for its cost. Fertile sources of failure in any investigation are too much "inherited" knowledge and too many theories on the subject.

8 In a proper investigation of any subject theories should be disregarded as much as possible, and facts sought for. After the facts are known, a theory to explain them and to indicate a direction for further investigations may be very useful, but unless we are willing to give up such a theory that does not distinctly help us, it is apt to do more harm than good.

9 With regard to Mr. Taylor's paper, I think, and I believe Mr. Taylor will agree with me that great as are the advantages to be gotten from a knowledge of the laws of cutting metals, to the engineering fraternity at large they are small compared to the value this investigation has as a part of the general subject of task management, the importance of which it is impossible to over-estimate.

10 So interested is Mr. Taylor in this subject and so convinced is he of its value in general, that he has for several years devoted much of his time without compensation to people who were trying to establish it, and is now always willing to help anybody interested in the subject.

HENRY R. TOWNE Mr. Taylor's paper on "The Art of Cutals" is a masterpiece. Based on what is undoubtedly the largest, and most exhaustive series of experiments ever con- n this field, its summary of the conclusions deduced therefrom s the most important contribution to our knowledge of this which has ever been made. The subject itself relates to the on on which all of our metal working industries are built. out 60 years ago, American invention lifted one of the earli- most universal of the manual arts from the plane on which ood from the dawn of civilization to the high level of modern cal industry. This was the achievement of the sewing . About 30 years ago, American invention again took he oldest of the manual arts, that of writing, and brought it ithin the scope of modern mechanical development. This achievement of the typewriting machine. The art of forming pering metal tools undoubtedly is coeval with the passing of e age, and therefore in antiquity is at least as old, if indeed it outrank, the arts of sewing and of writing. Like them, it has d almost unchanged from the beginning until nearly the time. The work of Mr. Taylor and his associates has lifted e from the plane of empiricism and tradition to the high level rn science, and apparently has gone far to reduce it almost to t science. In no other field of original research, that I can as investigation, starting from so low a point, attained so high as the result of a single continued effort.

easured by originality and comprehensiveness Mr. Taylor's ndoubtedly is the most important thus far contributed to the tions of this Society. With perfect modesty it makes no o sole credit for the achievements it records, awarding due o all who were associated in the work, and recognizing that the self was made possible by the rapidly developing opportunities nodern materials, processes, and machines have made avail- t which previously had not been fully appreciated or utilized. Taylor is due all credit for being among the first to perceive pportunities, to appreciate their possible significance, and, idless patience and consummate skill, maintained through s with unfaltering persistence and despite all discourage- to carry forward his undertaking to its successful issue.

he title of Mr. Taylor's paper does scant justice to the scope of k which it records, for incidentally to its main purpose this cluded subordinate investigations hardly less radical, even if mportance, than the main issue. Chief among these was the

development of what is now best known as the "Taylor System" of shop management, itself a discovery of fundamental importance, the influence of which will be felt ultimately and permanently, not only in the metal trades but probably in all organized industry. Less fundamental, but still of universal interest and value wherever power is transmitted from a central source to large groups of power-driven machines, is the determination by Mr. Taylor of more correct and efficient rules for the use of leather belting than were previously known. Another distinctive topic covered by his work is the proper forms of cutting tools and improved methods of making and maintaining such tools. Still another, and in some respects the most novel and brilliant of these many contributions to technical knowledge, is his adaptation of the slide rule to the determination of equations involving twelve variables, by a process so simple as to bring it within the reach of any skilled mechanic of fair intelligence.

5 The Society of which Mr. Taylor is the President, the Profession of which he in an honored member, and the industrial world are all to be congratulated on the achievements of which Mr. Taylor's paper, voluminous and comprehensive as it is, constitutes but a partial and inadequate record. While probably that paper is by no means the last word to be spoken on the subject to which it relates, certainly it is the most important and authoritative which has yet been uttered.

MR. JAMES M. DODGE I want to just say one word about one word, and that is the word "task." It is a pity that our language has not another word that is more applicable to the meaning that Mr. Taylor gives to the word, but Mr. Taylor agrees with me that our language does not give us the exact word needed. Now, the "task" set by the Taylor System isn't a club which makes a man do twice as much as he did in the same way he has been doing it. The "task" set by Mr. Taylor, by the use of the prescribed tools and methods lightens the task; it does not add to the labor performed. It cuts out the unnecessary motions, and it renders the motions made more useful and more efficient by something supplemental. These motions are made, if we can use such an expression as suiting a man's comfortable position or accomplishments. The men themselves who are doing these "tasks," say that they go home less tired than they used to do when they set their own tasks. So I say again that I regret that we have not a better word than task which according to our childhood lessons implies bother or burden, something which our teachers meant as a punishment to us. It is not a task; it is a help to the employee.

MR. CALVIN W. RICE As an incident to the introduction of system in a certain shop it became necessary to conduct the experiments of which the presidential address is a résumé. I say an incident, but it would probably be more correct to speak of the address as a record of many incidents to the introduction of the Taylor system.

2 The system is universal of application, and the mastery of the art of cutting metals was simply one of many things to do to make a success of the system. As the system is applied to other industrial establishments, we may in turn expect papers on the arts pertaining to them, such as the art of bleaching cotton goods, etc.

3 This situation is not peculiar to the Taylor system. Mr. Edison has been busy the last few years not so much in inventing a storage battery as in the development of the art of the manufacture of materials that go into the composition of the battery. Were it not a digression I would like to go into the subject in detail.

4 Therefore the good from modernizing engineers is far reaching. This fall I had the opportunity to visit the Sayles Bleacheries, located near Pawtucket, R. I., where the Taylor system is being introduced, and with your permission, I will offer as a discussion on this paper a few remarks on what I saw there, the object being to show the applicability of scientific method and the benefit derived from such application to any form of industry.

5 It is well to observe here that one cannot effect these improvements without, first, complete submission of the management of affairs to the one introducing the system, and, second, additional people to the regular establishment. There is no compromise between the old and the new because they are fundamentally opposed. It is only folly to try it because it is a physical impossibility for the regular staff both to conduct the regular business and simultaneously master and apply the new system.

6 In the Sayles Bleacheries I was permitted to compare the record of the output of certain rooms before they began to introduce the system with what is now being done,, and even in the most simple matters, namely, folding cloth, the increase in output was very great, individual cases fivefold, and the increase of individual wages 20 to 40 per cent. The cost per piece was of course reduced.

7 Improvements in other bleacheries, competitors say, have of course been going on also, so that the Sayles have no monopoly in this regard, but what they do have over their neighbors is a better class of employees with higher individual wages, freedom from labor difficulties, because the Taylor system does not conflict with the bulls of labor unions, and more than all, an organization capable of indefinite expansion to meet any emergency.

8 It would be out of place, and perhaps breach of confidence to go into further details. Suffice it to say, that in this world of competition intelligent organization based on scientific investigation is the *sine qua non* of success and that no amount of work or years of investigation necessary to obtain the result should deter the investigator.

MR. J. SELLERS BANCROFT I wish to add a little contribution to the historical side of Mr. Taylor's paper, with reference particularly to the shape of the cutting tool, and the means for producing it.

2 In 1869, I made a number of experiments at the works of William Sellers & Co., where I was then shop foreman, and demonstrated that the round-nosed tool would take a cut having a feed from 25 per cent to 33 per cent coarser than the diamond point tool would take in the same material and same depth of cut, with the added advantage that on cast iron the final chip being so much thinner the material was left in much better shape for the finishing tools. The advantages of this form of tool, and the importance of having uniform angles of clearance and top rake, demonstrated the importance of having these tools ground by machine, and in 1874 Former slide rests, arranged to attach to regular grindstone boxes, were put into service and used regularly for this purpose. The advantages of this system were so apparent that in 1884 a more fully organized machine was constructed, using a special form of emery wheel on which all tools used on the machines, whether for lathe or planer, external or internal work, or screw cutting, could be finished to definite angles and sizes, and thereafter all tools used in the shops of William Sellers & Co. were so ground.

3 In 1883 a long series of experiments were tried on a 48 inches lathe to determine the power required for various depths and widths of cut on both steel and cast iron, and the information thus gained was used thereafter in the designing of machine tools.

4 So far as I know, Mr. Taylor is undoubtedly the pioneer in experiments leading up to the discovery of the conditions which permit the use of high speed in cutting metal, both as relates to the shape of the cutting tool and the relation of depth of cut to feed and the method of producing high speed tools, which discoveries have practically revolutionized machine shop practice. But I think that the changes made by Mr. Taylor in shop management and methods of handling work have been far more important, as regards the increased production of any given machine, than the cutting tools themselves, important as they are.

MR. H. K. HATHAWAY It is to be hoped, and is highly probable, that many superintendents and managers of machine shops will undertake to make use of the invaluable data that Mr. Taylor has so generously made available to thousands, who, through limited facilities and time, would otherwise be unable to acquire more than an inadequate and superficial knowledge of this vitally important branch of manufacturing, and that as a result the manufacturing world may be as greatly benefited by exact knowledge of what can be accomplished in cutting metals, as it has already been benefited through the invention and general use of high speed steels.

2 I should like, however, to call attention to a grave danger that will confront all who undertake to attain the results that Mr. Taylor has shown to be possible, which, unless properly guarded against, will cause all such attempts to end in disastrous failure and disappointment. This danger is, that despite the fact that Mr. Taylor has clearly stated the necessity for first establishing such conditions as will make it possible to always and definitely answer the "questions which must be answered each day in every machine shop," as to the kind of tool, the feed, speed and depth of cut to be used, and to make use of the answer after it is given, many will undertake to apply the knowledge contained in Mr. Taylor's paper without any preliminary preparation to insure the successful outcome of such an attempt.

3 In many cases such an effort will cease after the workman running the machine, when told to use a certain feed, speed, or depth of cut, replies in a convincing manner that the machine won't stand it, or that the job he is working on is of such a peculiar nature that such a heavy cut would spoil it by "springing" it or making it come "out of round." If the foreman is still unreasonable enough to insist upon his trying it, he will either quit, or proceed, more in sorrow than in anger, to prove the truth of his statements, and the foreman will probably lose heart after the following things happen: The cone belt will slip and have to be tightened; next the countershaft belt will slip and have to be tightened, then if the belts pull the cut without breaking in two or pulling out at the lacings, it will be found that the carrier, driver or chuck will not hold the job.

4 After surmounting these difficulties and having the tool break or fall down through having been improperly treated and ground, the foreman will find that for about three hours he has neglected important matters in other parts of the shop and will conclude in the future to mind his own business and leave such matters as feed and speed to the judgment of the man running the machine, who from his daily experience ought to know better what the machine and tools will do than anyone else in the shop.

5 Having been through all this myself, I know pretty well the opposition and difficulties that will be encountered, and feel that too much stress cannot be laid on the importance of overcoming them before they have a chance to arise, and I have become a strong believer in the "ounce of prevention" theory, provided it is applied, not in a spasmodic manner, but systematically and continuously.

6 To cite an instance of what may be expected when one undertakes to speed up the average shop, I should like to mention an experience of my own that happened a few years ago, when after having passed through the various stages from apprentice to foreman, or "overseer," in the machine shops of the Midvale Steel Company, where I was accustomed to see rapid and heavy cutting, and also men obeying orders as to speeds, feeds, etc., and to have belts heavy enough and maintained to a tension that assured their pulling all that the tool would stand, I accepted a position as superintendent with a small concern, where the workmen, under the sole direction of one "overworked foreman," ground their tools to suit themselves, repaired and cared for their own belts, and followed their own judgment or inclinations as to the feeds, speeds, cuts, and kind of tools be used.

7 I was amazed at the light cuts and slow speeds I found in vogue, as well as the many peculiar shapes of tools in use, and attempted at once to get things up to the speed that I had been used to at Midvale, with the result that I encountered all the obstacles previously enumerated and found that the custom in that shop, when a belt slipped, was to reduce the speed or feed to a point where it would pull, as the workman reasoned that it was less trouble to do so than to tighten the belt.

8 Another drawback to using the proper feeds and speeds was that the tools were of every conceivable shape and kind of steel, a bar or two having apparently been bought from every tool steel salesman who came along, and as the workman had no means of identifying the tools made of good high speed steel from those made of old carbon or early self-hardening steels, he ran the speed suited to the latter, to be sure that his tool would not give out during a cut.

9 After I had managed to get the belts, tools, and driving mechanism on a few of the machines in such a condition that something like the proper speeds and feeds could be used, I found that it was utterly impossible, with one "overworked foreman," (who did not take very kindly to my notion of speeding up, anyway), to insure such conditions being maintained continuously, and that while I might get a workman to run the proper speed on a certain job today, if left to himself

the next time that job came up he would be running the same old speed and have the same old reasons for doing so.

10 About this time I learned another fact that has since been of great value to me, and that is, it is exceedingly unwise to expect to attempt to correct the evils of years of bad management and faulty shop practice, or to bring about a change from the minimum of efficiency to the maximum of efficiency in a few days or weeks or even months.

11 In the shop referred to, I attempted to install the premium plan, based on carefully kept records, which I later found to be absolutely inaccurate and unfair, and to get the shop up to the speed that I knew to be possible, in about three months' time, with the result that at the expiration of that time I had a strike on my hands which pretty nearly put the company down and out, and solely because I began at the wrong end, instead of first taking steps to insure the success of my efforts; first, by standardizing, and making such improvements in the belting, tools, and appliances as were necessary in order to make it possible to get the same results as were being attained at Midvale; secondly, by providing a system or mechanism for keeping them up to the standard once attained; thirdly, by replacing the one "overworked foreman," who was expected to know it all and do it all, by a planning department which would each day assign for each workman a definite task to be performed in a definite time, and prepare instruction cards showing just how each job should be done and what speeds, feeds, and tools should be used, and by several functional foreman in the shop, each of whom would have specific and well-defined duties, for which his temperament and training fitted him; who would coöperate in seeing that all work was done in the manner planned and that the standards were maintained.

12 It seems to me that my undertaking to apply in this shop, the feeds, speeds, and cuts that I had used, and seen used continuously at Midvale, is analogous to undertaking to apply the information on the "Art of Cutting Metals" contained in Mr. Taylor's paper, in the average machine shop without any previous preparation to insure a successful outcome of such an undertaking, and it is devoutly to be hoped for their own sakes, and in fairness to Mr. Taylor, that all who do hope to benefit by Mr. Taylor's vast experience in this line will begin at the right end and in the right way which Mr. Taylor has pointed out and which I am convinced, from my experience in the matter, lies in the application of the principles set forth in his paper on "Works Management," and which can only be successfully applied through a system of functional management, where every man from

the manager down has a definite task to perform in a definite way and by the establishment and maintenance of rigid standards.

13 Unfortunately such a system as Mr. Taylor's cannot be bought and delivered in a box, but must be installed step by step until the final goal is reached, when a definite task is given each workman each day in advance with detailed written instructions and an exact time allowance for each element of the work, and this installation calls for such an amount of hard work, close and incessant following up, and minute study of conditions as to make it impossible for any man who has routine work to do in connection with the running of a plant, to undertake it with any hope of success, but will call for the undivided attention of an experienced man, who must have the heartiest and most sincere backing and support of the management in the face of the opposition and prejudice that is sure to be encountered. Even then, there will be times during the period of revolution from the old to the new system of management, when it will appear as though the business is going to ruin, when the greatest faith in the soundness of the principles upon which this system is based will be required to carry one through them, but the reduced costs, increased output and harmony that are bound to result in the end are sure to pay many times over for the labor and expense incurred in making the change.

Mr. John T. Hawkins Nothing but admiration can be entertained for the indefatigable, exhaustive, and methodic work set forth in President Taylor's paper, extending as it has through so long a period of time, on the somewhat narrow question, however, of how best and most economically to rough out, preparatory to the finishing processes, castings of iron and steel, or forgings of the latter metal of considerable dimensions; for to these the paper seems to be confessedly and practically confined.

2 There is in it, however, for me, a most regretful feature, which is, that if carried to its logical conclusion it would ultimately eliminate, or at least very greatly emasculate the real mechanic.

3 The writer's immediate progenitor was of that old school of mechanics scarcely now known in the industrial world except by name, as the all 'round man. He was at once a blacksmith, machinist, and pattern-maker. He could do a job in the foundry when necessary and was no slouch as a draughtsman. He could forge an anchor or make a violin; and what's more, could creditably perform upon the fiddle when finished.

4 It was in the shops of such a father that the writer imbibed

much of what has now become scarcely more than memories and is well nigh obsolete in the mechanical world of today, and what certainly contrasts greatly, so far as physical and mental capacity of workmen is concerned, with the quality of mechanic that would suffice under the slide rule system described by Mr. Taylor.

5 Time was when what has been felicitously termed "finger wisdom," coupled with the ordinary complement of brain, constituted the productive capital of the mechanic. These joined to that salutary disposition in a workman to industriously apply those attributes to the production of the most and the best; that carrying of their consciences with them when they went to work in the morning which obtained in the older days, presented a state of things in industrial concerns such as no longer obtains to any satisfactory extent; it is with regret, therefore, that the writer sees, or thinks he does, in the adoption of such a system as is illustrated by Mr. Taylor, an inevitable tendency toward the supplanting of the old-time finger wise and thinking mechanic with scarcely more than unthinking automata; and I have great fears that to thus narrow down and circumscribe the man would be disastrous in the long run.

6 Of course, I have long ago realized that in these days of labor-saving machinery and division of labor such a type of mechanic as I first described would be in any modern establishment a most expensive superfluity, if not indeed an impossibility; and I am very far from advocating that every mechanic should now be expected to "know it all." In this specializing age I recognize that both the maximum of productivity and perfection of work come greatly from narrowing the field of a mechanic's activity; as indeed obtains in the professions and in every sphere of human endeavor; and the fact is, that during the last 50 or 60 years so much has been added to the sum of human knowledge that in the machinist's vocation alone, the total has become too great for the average man to master and to perform well and profitably. It is no less essential, however, that the mechanic should still be, to whatever comparatively narrow field he might be confined, an intelligent, brainy, finger wise man. It would generally, and in the long run be vastly better for all concerned, even if a man learned nothing more of a machinist's vocation than would pertain to the roughing out of heavy work of iron and steel on the appropriate machine tools, with his cutting tools all chosen, fashioned, and ground for him, as has long been the practice in the best shops as a branch of tool room work, to learn this well and all that is implied in and pertains to the art of such roughing; to become finger wise and head wise in his chosen narrow occupation,

than to have his mental efforts confined to so narrow a limit as is involved in the slide rule system described.

7 It seems also quite obvious that the highest productivity and pecuniary advantage both to himself and his employer ought to be more likely to come from the conscientious work of such a man who learned to rely upon his own head and his own hands, than from one only so poorly equipped as would be necessary where he depended upon these slide rules to do his thinking for him.

8 The writer's sympathies with the competent, thinking mechanic are so great that he prefers to believe that in the long run there is much more to be looked for in the furtherance of the productivity of any machine or set of machines through some such system as will be described at a later session in a paper by Mr. Magnus W. Alexander, entitled "A Plan to Provide a Supply of Skilled Workmen," the system being in operation at the Lynn works of the General Electric Company, and in similar systems which are in operation in other parts of the country, than can possibly, in the long run, result from such as the slide rule system in question.

9 There is, however, one aspect of this matter which leads the writer to look upon the narrowing, emasculating feature of this slide rule system with more toleration than he could otherwise do; and to choose, as it were, between two evils.

10 Such a system, if it could be carried extensively into use in the machinist's vocation, and made to appeal, as it may, to a man's cupidity, would have such an effect upon the horrid work of the labor unions as in due time to put them practically out of business, and render what is known in trade union parlance as the "closed shop"—most appropriately and expressively so named—a curiosity.

11 If a man whose capacities were only sufficient to operate under the slide rule system were told that he could get a job, where, while increasing his employer's profit by 40 per cent he could add to his own receipts 35 per cent, provided of course he subject himself to the orders of his employer in preference to and in place of those of any union, he would be reasonably sure to jump at such a chance; and the more certainly if he remembered that he could save in addition all fees, dues, fines, and assessments demanded and enforced by his union.

12 The writer has for a long time been as deeply interested in the suppression of closed shop unionism as he always has been in the elevation of the competent mechanic and workman. As a typical case let me relate that while managing engineer of a concern running a machine shop employing about 100 men, as an adjunct of an

extensive special business, I was also a minority stockholder in the whole concern. The majority powers, after a long struggle, consented to the making of the whole industry a "closed shop."

13 I may say here in parenthesis that had I been a majority stockholder you may depend that it never would have become a closed shop.

14 Soon after this change was effected in watching a man running a milling machine, I found that he was using a feed which my experience of more than 50 years, both as a workman and employer, told me was more than four times too slow. In short, that when the extra cutter grinding made necessary by this mere scraping process is considered, this man was in receipt of about five times more than he really earned while making five machines necessary to do the work of one.

15 Suffice it to say that when he was remonstrated with by me I was referred by him to the "shop steward," an official of the union empowered to regulate all such questions and to keep the product down to a labor union standard. Suffice it again to say (and in order to forestall my friend Mr. William Kent, who is very likely to ask why I did not do something about it) that after all possible persuasion on my part to prevent the establishment of the closed shop, without avail, I very soon thereafter resigned my position and sold my stock to the then majority holders, rather than continue a party to such a state of things.

16 Now, I can readily conceive that if the slide rule system of Mr. Taylor was applied to such as this man and to men in the many other variations and ramifications of the machinist's vocation, such an outrageous state of things as I have just described would soon become impossible; but I am afraid that we could never hope for such an extended application of that system as would become necessary to that end; and if we could thus extend the system, who is there of us, rejoicing in the title of mechanic, or machinist, or engineer, if you will, to complacently witness such a change? For myself, I feel that it would not be a consummation very devoutly to be wished.

17 I have become so greatly impressed of late years with the great necessity for an intelligent and earnest crusade in the direction of educating the coming generation of mechanics up to their own best interests and capacities, as the most efficient barrier to the growth of trade union evils that I look with suspicion upon anything which may tend to lower his mental status; but owing to the extent to which I have fallen into "the sere and yellow leaf" after more than 60 years of

active effort as machinist, engineer, and employer, always striving to make two blades of grass grow where before grew but one, it has become quite an impracticable thought for me. If I could, I should try to revolve backward, as it were, in more respects than one and endeavor to restore something more of the old-time conscientious, faithful, intelligent, finger and brain wise mechanic.

PROF. L. P. BRECKENRIDGE We must certainly be greatly impressed with the magnitude and value of the work which has resulted in the paper presented to the Society by President Taylor entitled "On The Art of Cutting Metals." The Society is to be congratulated in being able to present to the manufacturing industries of the world the invaluable material now so generously contributed by Mr. Taylor and his associates. We have all been allowed glimpses of this work from time to time and have marveled at even some of the smaller details, but when we come to look down the long vista of 26 years and realize to some extent the immense expenditure of time, money, and effort, the careful, minute, painstaking researches and patient devotion of noted specialists, all gradually leading to this final monumental accomplishment, and when we realize what it all means to the future advancement of industrial works, we must acknowledge that the work presented will doubtless be a classic in this particular field of engineering literature for many years to come. The possibilities of coöperation as pointed out by Mr. Taylor have been taken advantage of in a most admirable manner, and we must express the feeling that only a man of extraordinary patience, ability and tact could have been the guide and inspiration of this intricate task.

2 The reference of Mr. Taylor to the work undertaken by the Engineering Experiment Station at the University of Illinois by Mr. H. B. Dirks and myself is appreciated. We realized at the time and realize to a much greater extent now, the insignificance of our contribution to this subject. We did have, however, two important thoughts in our minds in connection with our work:

a That Illinois industries were not taking advantage of the opportunities offered by the use of modern high-speed steels, and that our manufacturers could be educated to the fact that cast iron could be turned more rapidly than had been the previous practice. We felt that their attention could be called to its possibilities by a series of experiments such as were published, even if these experiments did not settle many of the important problems connected with the use of high speed steel.

b We were desirous of placing before the students of the College of Engineering a working illustration of the use of high-speed steels in cutting metals.

3 It is possible that these two objects were in a measure accomplished. Although we spent but about 14 months, and expended only about $2500 on our work, we did go far enough to appreciate the impossibility of any one experimenter accomplishing very much, as is corroborated by Mr. Taylor in his present paper.

MR. H. C. H. CARPENTER[1] Mr. Taylor's valuable work "On the Art of Cutting Metals" will rank among the most remarkable practical scientific researches ever published. An investigation which has extended over 26 years, which has been rendered possible by the collaboration of five men, each of whom appears to have possessed a special qualification for some one branch of this many sided work, and the account of which is based on some fifty thousand recorded experiments, is probably without a parallel. The ground covered is so extensive that it is almost impossible for any one man to form anything like an adequate judgment of the research as a whole. The most that can be attempted is an estimate of that portion in which a writer may have special experience.

2 The history of the evolution of the art of cutting metals during the last 26 years set forth by Mr. Taylor has appealed to the writer with special interest. It is one of the comparatively rare instances in which results of the highest importance have been reached only after long years of patient grappling with difficulties of the most intricate and baffling character and in which the number of "independent variables" has bewildered the most powerful intellects. This quality places it among those types of research whose problems are only solved by the "patient intending of the mind."

3 Mr. Taylor has courteously referred, and indeed given great prominence, to two investigations of the writer's which bear upon "the art of cutting metals," and the latter would like to take this opportunity of expressing his gratification both for the value attached to them by so eminent an authority, and for the substantial correctness with which they have been interpreted. A few minor corrections are however necessary, and these will be dealt with at once.

a The temperature at which hardening changes to softening carbon on cooling is stated to be 760° C. This is rather too high for most steels. For pure carbon steels it is about 700°–720° C. For special steels, e.g., the chromium or chromium tungsten steels, it varies between about 710°–760°.

[1] Professor of Metallurgy, Victoria University, Manchester, England.

active effort as machinist, engineer, and employer, ... make two blades of grass grow where before grew ... become quite an impracticable thought for me. If ... try to revolve backward, as it were, in more re... endeavor to restore something more of the o... faithful, intelligent, finger and brain wise m...

PROF. L. P. BRECKENRIDGE We m... pressed with the magnitude and value ... in the paper presented to the Soci... "On The Art of Cutting Metals." ... in being able to present to the m... the invaluable material now s... and his associates. We ha... ...bel ... from time to time and b... ...the W ... details, but when we ... tested t ... years and realize to ... ...ools in the Man ... money, and effort. ... patient devotion ... ...to suspend judgment ... final monumen... means to th... ...made to the following quotation fro... acknowled... ...uress: "Our original investigations showe... particula... ...hardness was seriously impaired by heating tools ... The p... 1200° F. (650° C.), and that the quality of red hardne... beer... entirely removed by heating them up to 3150° F. (73... ex... Now it will be noted that neither in the heating nor ... curves shown by Professor Carpenter any critical p... shown at these temperatures which are the critical t... atures so far as we know for high speed steels, and th... the critical temperatures affecting red hardness." The h... but not the cooling, curves bear on this point. Alloy ... shows no break in the curve, but Alloy No. 16, pre... cooled from1200° C., shows a change of slope at about ... which is continued until 735° C. This is almost exact ... range referred to by Mr. Taylor. And if the other cu... the paper ("Journal of the Iron and Steel Institute," 19... consulted it will be noticed that some of them give ... breaks. Accordingly, it is the writer's view that the cur... more in agreement with the results of practical test... Mr. Taylor has given them credit for.

4 Before discussing a few of the extremely interesting ... raised in the address, it appears desirable to take note of the foll...

b Mr. Taylor's reading of the significance of the changes of slope of the curves in reference to critical changes is correct. But within wide limits the general character of the curves is independent of the rapidity with which the heating and cooling takes place, and this is one of the chief advantages of the differential over the direct method of taking such curves. In the former method the alloy is cooled against a neutral metal or alloy which is known to give a smooth cooling curve; in the latter the alloy is cooled against time. The former, in addition to being much more sensitive, is also more philosophical.

c The writer does not agree with Mr. Taylor's statement as to the inferiority of Dr. Matthews' steel as compared with recognized high speed steels in the cutting tests. Although the former did not stand up to its work in machining hard steel, it behaved extremely well in cutting medium hard steel, and on the whole, satisfactorily in machining soft steel. It was tested under less advantageous conditions than the tools in the Manchester tests. And it seems fairer to suspend judgment unless further tests are made.

d Reference must be made to the following quotation from Mr. Taylor's address: "Our original investigations showed that red hardness was seriously impaired by heating tools above 1200° F. (650° C.), and that the quality of red hardness was entirely removed by heating them up to 3150° F. (730° C.). Now it will be noted that neither in the heating nor cooling curves shown by Professor Carpenter any critical point is shown at these temperatures which are the critical temperatures so far as we know for high speed steels, and therefore the critical temperatures affecting red hardness." The heating, but not the cooling, curves bear on this point. Alloy No. 14 shows no break in the curve, but Alloy No. 16, previously cooled from1200° C., shows a change of slope at about 622°, which is continued until 735° C. This is almost exactly the range referred to by Mr. Taylor. And if the other curves in the paper ("Journal of the Iron and Steel Institute," 1905) are consulted it will be noticed that some of them give similar breaks. Accordingly, it is the writer's view that the curves are more in agreement with the results of practical tests than Mr. Taylor has given them credit for.

4 Before discussing a few of the extremely interesting issues raised in the address, it appears desirable to take note of the following

important conclusion arrived at by Mr. Taylor: "All of these facts indicate clearly that the methods as yet devised by scientists for determining the most important quality (*i. e.*, red hardness) in the new high speed steels are ineffective." When such a statement is made with a wealth of practical experience and experimental results behind it, the safest course is to accept it without demur. Probably no one who studies this research will challenge Mr. Taylor's conclusion that the only reliable guide or index to the behavior of cutting tools hitherto devised consists in making standard cutting speed tests. But as one of the scientists referred to, the writer would like to state that his aim in undertaking researches and contributing papers in the field was far less ambitious than that of supplying a simple and reliable index to the property of "red hardness," being, viz: initially an attempt to arrive at the rationale of the heat treatment of high speed tool steels in current use.

5 A point of the utmost importance is the distinction drawn by Mr. Taylor between "hardness" and "red hardness." This point is labored with considerable emphasis in various passages, but the following quotation will suffice to define his position. "He," *i. e.*, the author, "has failed to recognize the existence of 'red hardness' as a property of these steels entirely independent of hardness. We would again call attention to the fact that the highest degree of 'red hardness' can be found in these high speed steels when accompanied either by the highest degree of hardness on the one hand, or by a very considerable degree of softness on the other hand." If the writer has understood Mr. Taylor correctly, he draws a sharp distinction between the hardness in virtue of which a tool cuts at the ordinary or comparatively low temperature, and the hardness in virtue of which a high speed steel cuts at a red heat (red hardness).

6 This may be true, but the following considerations appear to indicate that the facts observed and recorded by Mr. Taylor and his co-experimenters can also be explained without assuming a difference of property. The writer is well aware that the simplest explanation is not always the true one, but until it has been shown to be wrong there is no need to have recourse to a complex one involving rash assumptions. Time unfortunately prevents him from developing the explanation to the extent it really requires to bring it into line with the numerous facts marshalled by Mr. Taylor in support of his view, but the following general exposition may be sufficient to enable application to be made to particular cases.

7 The relations between carbon and iron must first be considered. The most complete state of mutual solution of these elements appears

to correspond to austenite (white polyhedra); the next, to martensite (acicular structure); the next, to the varieties of sorbite (almost structureless), and the least, to pearlite (banded structure). In practice, pure austenite has never been obtained. The method adopted for keeping the elements in solution, viz: quenching in various media is not sufficiently rapid to prevent some of the carbon (in what form is immaterial) from separating, and the result is a mixture of austenite and martensite. In pure carbon tool steels the hardening is carried out in such a way that as far as possible the iron and carbon are in the form of martensite. This is the hardest modification obtainable. If an attempt is made to cut work at a high speed with such a tool, it fails because the martensite changes rapidly at 200°–300° C. into the sorbite varieties, and ultimately into pearlite, which are all soft.

8 But the addition of tungsten and chromium in the proportions present in high speed steels enables the complete solution of iron and carbon to be maintained by rapid cooling from 1200° C. below 620° C. (1150° F.) and the result is that such steels, as treated for cutting, possess the austenitic structure. As Mr. Taylor points out, the steels in this condition can readily be filed by ordinary hardened tool steel. The reason for this is well known; viz: that austenite can be indented by martensite.

9 What happens when these high speed austenitic tools are put to cut work? The best of them are unaffected by temperatures not exceeding 500°–550° C., the reason being that the chromium and tungsten combined prevent the complete drawing of the temper which takes place in pure carbon steels. Somewhere about 600° C. the austenitic changes to the martensitic structure. *This is the red heat at which the tools cut best.* At higher temperatures the martensitic is replaced by softer materials and the tools break down. According to this explanation the high speed steel possesses at about 550°–600° C. the same hardness that the pure carbon steel possesses at ordinary temperatures. And no distinction seems necessary other than that the hardness is manifested at different temperatures. The hardness itself is the same in the two cases.

10 There is one weak spot in this explanation, viz: the writer has examined cases in which no martensitic structure appeared to be formed from the austenitic structure. Either the tempering proceeded on other lines or the martensite stage was missed. Accordingly he does not wish to press the above exposition, but rather to suggest it as a possible coördination of the facts recorded by Mr. Taylor.

11 It has the merit of offering an explanation of the curious

fact mentioned, that "if the percentage of tungsten is increased much beyond 19 per cent, even although the chromium is also increased in quantity, the tool diminishes in red hardness." It is well known, through the work of M. L. Guillet, that the alloy steels with austenitic structure vary considerably in the ease with which they pass into the martensitic stage, and indeed that some of them do not pass at all, and it appears to the writer that No. 14 tool containing 24.64 per cent of tungsten and 7.02 per cent of chromium, may be one of these, in which case the reason for its inferiority of cutting properties is clear, viz: because the martensitic, *i. e.*, hardest structure, is never formed.

12 Mr. Taylor's statement that the red hardness of high speed steels is practically independent of carbon between the limits of 0.32 and 1.28 per cent, is a fresh piece of the kind of evidence that has been accumulating during recent years that carbon can no longer enjoy the unique position as a hardening agent it has been hitherto supposed to possess. It follows clearly from his experiments that in high speed steels the capacity to cut work at a red heat results from a combination of variables, more especially carbon, chromium, and tungsten, in which it is impossible to assign a more important function to one variable than to any of the others.

13 This leads up to what the writer regards as the most baffling question that arises out of that section of the address entitled "Investigations made to find an explanation or theory for the phenomena connected with chromium tungsten tool steels," viz: what is the part played by chromium in high speed steels? As a result of the first of his researches quoted by Mr. Taylor ("Journal of the Iron and Steel Institute," 1905, 433-473), the writer was enabled to conclude that the rationale of the advantageous presence of tungsten in these steels is fairly evident; viz: that its action consisted in altogether preventing under suitably chosen conditions changes in iron carbon alloys which would have for their result the softening of the material and its consequent unfitness for use; and, further, that it imparts to such steels a high resistance to tempering. On the other hand, it was shown that chromium not only does not retard but actually hastens the conversion of hardening to softening carbon on cooling, and the microscopic evidence was all against the hypothesis of special chromium carbides or double carbides. In other words, the action of chromium was shown to be the opposite to that of tungsten. The question naturally presents itself, "What is the part played by an element which by itself appears to act in a direction diametrically opposite to that desired?"

14 In formulating the view that chromium and tungsten differ fundamentally in their action, the writer found himself in opposition to the current view, viz., that chromium and tungsten acted similarly. The peculiar action of chromium is, however, now recognized by Mr. Taylor. He shows that the Mushet self-hardening steels (1894–1900) which contained tungsten, manganese, and silicon as their principal alloy elements, were different from the present day high speed steels containing tungsten and chromium (tungsten and manganese both act as retarders of critical changes; *i. e.*, similarly); and he emphasizes the difference between chromium and manganese in the passage "*Chromium is the element which in combination with tungsten produces the new quality of red hardness and not manganese.*" The distinction between the actions of chromium and tungsten is drawn in the passage: "A tool without chromium or with very low chromium, even though there is a proper percentage of tungsten present, does not produce a high speed steel even though the manganese be very low or very high."

15 The writer's attempt to coördinate hardness and red hardness in preceding paragraphs permits of application to the present question, as Mr. Taylor shows, even high tungsten steels are not high speed steels. Let it be supposed that these are austenitic steels of the non-transformable type (in which case they will not exhibit red hardness). Now let chromium be introduced. Its tendency will be to convert such steels into transformable ones because it has been shown to hasten the conversion of hardening carbon. In small quantities its influence may be insufficient to bring about the change, but it may be that in considerable quantity (such as the 5 per cent to 6 per cent mentioned by Mr. Taylor) it will cause the change from austenitic to martensitic structure at about 550°–600° C. The result will be a high speed steel possessing red hardness. This view can readily be put to the test of experiment, and the writer hopes to undertake this soon.

16 It appears possible to put forward now a scientific classification of the various types of cutting tools. Mr. Taylor groups them historically under three main heads, which will serve quite well for the writer's grouping, viz:

a The era of carbon tools (up to 1894).

b The era of Mushet or self-hardening tools (1894–1900)

c The era of high speed steels (1900 up to the present time)

Group *a* represents tools which, in virtue of the treatment to which they are exposed, exhibit maximum hardness at the ordinary temperature. They are martensitic steels. Run

at about 200° C. they soften, because at this temperature the martensite changes into sorbite, and ultimately pearlite. The rate of change is at a maximum in these steels.

Group *b* also represents similar tools of martensitic structure but the tungsten retards the rate of change of the martensitic constituent, and hence they can be used at higher temperatures than those in group *a*. Such tools, however, cannot be run at temperatures much exceeding 300°–400° C.

Group *c* includes tools which, after heat treatment, do *not* exhibit maximum hardness at the ordinary temperature. Their structure is austenitic; they can be filed by the tools classified in groups *a* and *b*. In virtue more particularly of their chromium contents, the change from austenitic to martensitic structure takes place at temperatures between 550° and 650° C, and consequently the tools possess maximum cutting hardness at these temperatures. This is the explanation of their characteristic property of red hardness.

.7 There is no reason for supposing that group *c* represents the ıl word in regard to the maximum temperature at which high ed steels can be run. On the contrary, Mr. Taylor's address conns internal evidence that his latest tools can be run at higher ıperatures than had been previously reached. A particular comation of chromium and tungsten or other elements may enable temperature to be pushed up to 700° C. Mr. H. Le Chatelier has vanced sound theoretical reasons for supposing (at any rate as long carbon forms an integral part of tool steel) that this temperature ınot be exceeded, because the rate of change is a maximum at)° or thereabouts.

.8 It may be very difficult to make this advance, and the writer nclined to agree with what he takes to be Mr. Taylor's forecast of economic future of this industry; viz., that it will probably pay ter to produce tools from cheaper materials than those now used ıt will run at the present degree of temperature than to experint with costly alloys that may be found to work at rather higher ıperatures.

MR. H. LE CHATELIER Few discoveries in the arts have been the asion of so many successive surprises as those of Mr. Taylor. At time of the Exposition of 1900 in Paris, nobody quite believed at t in the prodigious result which was claimed by the Bethlehem rks, but we had to accept the evidence of our eyes when we saw

enormous chips of steel cut off from a forging by a tool at such high speed that its nose was heated by the friction to a dull red color. The use of the high speed Taylor-White steels spread rapidly in our manufacturing plants; we became accustomed to them and were no longer astounded at their qualities. People did not even take the trouble to investigate the exact origin of this great discovery. The legend sprang up that the invention was made through the carelessness of a workingman, who had accidentally overheated this tool and thus, contrary to all predictions, had greatly improved it. People were satisfied with this explanation, and the originator of the discovery did not even take the trouble to deny it.

2 Some years later, he decided, at a time when people had ceased to speculate on the subject, to set matters aright. The new tool steels had been discovered as a result of an extended series of experiments which had been made with many hundreds of tools, and which had required during long years the permanent coöperation of both educated engineers and workingmen who devoted their time especially to this investigation. The legend had been disposed of. We thought this time surely that we knew the entire truth, but that was not at all so.

3 Mr. Taylor tells us now that the discovery of the high speed tools is merely one single step among a long series of investigations of equal importance; investigations which have been carried on for the past twenty-five years with the coöperation of some ten great industrial establishments, at an expense of nearly $200,000. The inventor informs us with legitimate pride that during all these years none of the results of these experiments had become known to outsiders. The promise of secrecy which had often been given merely verbally, had not been violated by a single manager or even by a foreman. We cannot too greatly admire such an example of probity in the arts.

4 It is very difficult, on rapidly reading a paper so full of important tables, formulæ, and conclusions, to grasp at once all of its salient features; it will be necessary to study it at leisure. Certain facts, however, will strike any engineer by the clearness with which they are set forth and will be at once adopted as the standard practice in our machine shops; for instance, this first thesis: "It has been found that the greatest economy is attained by running a tool at a cutting speed which will ruin it in one hour and one half." Or, again, the second thesis: "The cutting speed of a tool can be increased by 40 per cent, if its nose is kept wet with a heavy stream of water."

5 These are facts so easily verified that one is justified in being astounded with the author that they are not known to everybody.

The simplest discoveries are generally the most difficult ones to make, but they also involve in their application results of the greatest importance. The near future will show us the service which has been rendered to the mechanical arts by the generous publication of researches pursued with such uncommon perseverance.

6 But even now we can admire without reserve the scientific method which has controlled this whole work. It is an example unique in the history of the mechanic arts. We have all admired the researches of Sir Lothian Bell, on blast furnaces, and those of Sir William Siemens on the regenerative furnace; but notwithstanding the high scientific value of the work of these two great engineers, on reading their papers neither of them leaves an impression on the mind which can be compared with that of Mr. Taylor's paper. It is a model which every young engineer will have to study.

7 We believers in the scientific study of the arts have all been teaching our students that in investigating practical problems it is necessary, first, to accurately determine and define the various factors which enter into the problem; then to classify these factors according to the degree of their importance, and lastly, to study the effect of each of these factors as variables independently. But when we see how little respect is shown to these principles even in the laboratories of pure science; when we see the sovereign contempt with which they are treated by every technical man, we come sometimes to doubt our own teaching, and to ask ourselves whether after all we are not teaching our young men wrong methods.

8 And yet, the systematic application of these very methods—nobody can deny it any longer—has been preparing during all these years to transform machine shop practice from the domain of rule of thumb to that of exact science. The scientific method is now about to receive the crown which it deserves, thanks to the generous publication of the President of The American Society of Mechanical Engineers.

9 Among the varied subjects investigated by Mr. Taylor, the author of these remarks can select only one on which he can give a competent opinion. It relates to the chemical composition and to the thermic treatment of the high speed steels.

10 One of the essential points is the determination of the most suitable chemical composition for the new steels; the data of the original patent which are reproduced in the first column of the following table, showed too high a percentage of carbon, and too low a percentage in chrome and in tungsten.

	Taylor Patents[1] 1900	Le Chatelier[2] 1904	Gledhill[3] 1904	Taylor 1906
Carbon	2	0.5	0.55	0.67
Chromium.....	1	3	3.5	5.6
Tungsten.....	4	12	13.5	18
Vanadium	0	0	0	0.30

11 In 1904, after a comparative study of the best brands which at that time were to be found in the market, the composition of the second column of the table was recommended by me. Some months later, Mr. Gledhill published an almost identical composition, which was the result of experiments which he had made at the Armstrong-Whitworth works.

12 The composition recommended by Mr. Taylor in his presidential address differs notably from the preceding ones; the percentages of carbon, of chromium, and of tungsten are nearly 50 per cent higher, but the most important new point concerns the addition of a small quantity of vanadium and the absolute exclusion of molybdenum, which latter had, on the contrary, been considered by me as being rather superior to tungsten. Experiments made on a small scale did not enable us to recognize the irregularities which were due to the presence of this metal.

13 The difference between the hardness of the tool when cold and the hardness when hot is perhaps not so great as the author of the paper seems to claim; that the high speed steels are generally less hard than carbon steels suitably treated, is a fact recognized by everyone. It has already been demonstrated[4] that it is possible to make a clearly visible impression on the high speed tools, with a Brinell tool—something which is impossible on ordinary tools. The important characteristic in which the high speed tools and the carbon tools differ from one another is that the temperatures at which they lose their hardness differ widely; it varies from 300 degrees for carbon tools to 700 degrees for high speed tools. The high speed tool, which is the least hard while cold retains its hardness almost unimpaired at a dull red heat. These facts seem to be readily explained, as Mr. Osmond has shown, if we admit that the presence of chromium and tungsten increases still further the passive resistance to the transformation of the carbon on which, exclusively, the phenomena of annealing depends.

[1] French patent of June 12, 1900. Revue de Métallurgie, 1 bis, 187. 1904.

[2] Revue de Métallurgie, 1, 341. 1904.

[3] Iron and Steel Inst. Meeting, New York, Oct., 1904, and Revue de Métallurgie, 2 bis, 113. 1905.

[4] Revue de Métallurgie, 1, 342. 1904.

14 Mr. Taylor's observation regarding the absence of any relation between the quality of a high speed tool and its micrographical structure or the quantitative degree of its divers physical properties which can be measured, has nothing surprising in it. The same is true of carbon steels. If you compared two samples of one of these last mentioned steels, one heated to 780 degrees and cooled to 200 degrees, the other heated to 900 degrees and cooled to 250 degrees, the first will make an excellent tool, the second will be frightful. Nevertheless, their microscopic structure, and their electrical conductivity will be identical.[1]

15 We must not conclude, however, that the investigation of the physico-chemical properties of tool steels is useless. Such investigations can without doubt give necessary characteristics in steels for making tools of good quality although not all of the characteristics which are necessary for this purpose. Thus, carbon steel with 1.13 of carbon should show a structure which lies between that of martensite and troostite, and have a resistance equal to 1.4 times that of the annealed steel. These conditions are necessary in good tools: Steel which consists entirely of martensite, with an electrical resistance near 2 would certainly be too brittle, and unsuitable for use; steel consisting entirely of troostite, with resistance near 1, would certainly be too soft; a structure between martensite and troostite and a resistance 1.4 times that of annealed steel is certainly a characteristic of the best tool, but the reciprocal will not be true, these conditions alone are not sufficient to indicate with certainty a first-class tool.

16 It will doubtless be possible to find in the same manner for high speed tools, conditions of like character which are essential; but it is very doubtful, however desirable it may be, whether we shall be able to find all of the conditions essential for the best high speed tool.

17 The knowledge even of some of the characteristics necessary for a first-class high speed tool would be of great value. This would permit us to reduce the number of tests and to eliminate *a priori* such alloys as are without doubt useless. The great expense of making the experiments which are now necessary to test the efficiency of tool steels, renders any process valuable which would permit us to restrict their importance.

18 It seems as though it would be particularly desirable to make additional investigations in the direction of measuring the electric resistance and the magnetic properties of the best high speed tools.

[1] Revue de Métallurgie, 1, 186. 1904.

MR. FRED. M. OSBORN Probably the most interesting part of Mr. Taylor's paper to steel metallurgists is the tables and comments dealing with the way in which steel is influenced by varying proportions of certain special elements. While Mr. Taylor's general arguments appear reasonable, it would have been more useful if the deductions had been drawn from a series of analyses identical except so far as concerns the special element under consideration. The other groups of analyses are most complete and interesting.

2 As my work in the capacity of a director of Samuel Osborn & Company, Limited, is particularly connected with the manufacture of the original Mushet steel and its later development, Mushet High-speed Steel, and the former takes such an important place in Mr. Taylor's paper, the following brief statement regarding Mushet's discovery may be of interest.[1]

ALLOY STEELS

3 It is interesting to note that while Mushet was experimenting in 1868, he found that one of his trial bars had the property of becoming hard[2] after being heated, without the hitherto necessary water quenching. The element which gave the steel this property was tungsten. Mushet began to make and sell this self-hardening steel for lathe and planing tools: and "R. Mushet's Special Steel," as it was called, soon became famous. He was not successful in his business. After some three years he got into touch with the late Samuel Osborn of Sheffield, who in 1871 took over the Mushet process of making crucible and self hardening steels and introduced them, as their qualities and capabilities became known, into nearly every engineering workshop in the world. Tools of Mushet steel were naturally hard but it is believed that the late Mr. Henry Gladwin, who had assisted Mr. Osborn, was the earliest to show that a much better result was obtainable if the cutting portion was reheated after forging and cooled in an air blast.

4 It should be explained that Mr. Gladwin had introdued Mushet steel into the works and trained the blacksmiths in its working, and he found that tools which had been laid on the ground and cooled by the draught of air from under a door gave better results. It was later proved that tools which were reheated to a full scaling, or almost yellow heat, did even better work. It was difficult, however, to get the smiths to do this, and in the days before the introduction

[1] This statement was read by me before a Society of Engineers two days only before I received the advance proof of Mr. Taylor's paper.

[2] See also "Iron and Steel Institute Journal," No. 2, 1904, pp. 177–78.

of high speed steels, principals and managers took little interest in the heat treatment and working of cutting tools.

5 The introduction of Mushet steel enabled engineers to double and triple the output from their lathes, as the tools could both cut quicker and last much longer than those made of carbon steel. This steel was generally adopted and gradual improvements were effected, but a marked advance was made in 1900, when the Taylor-White discovery of a quicker cutting steel was announced to the world.

6 This was not really a discovery of a new heat treatment, nor of a new alloy or mixture. It was really a step beyond the one just described. The editor of the "Iron and Steel Magazine" takes this view, when he says in referring to the sometimes supposed distinction between ordinary self hardening Mushet steel and those special steels known as high speed steels:

> To us it seems, however, that no such distinction can be made between these two varieties of steels. Mr. Metcalf himself says that the discovery of high speed steel resulted from the overheating (possibly accidental) of some ordinary self hardening steel. This treatment, which had hitherto been considered ruinous when applied to self hardening steel resulted in imparting to it those wonderful high speed qualities now so well known. By this treatment the self hardening steel was converted into high speed steel. We want no more conclusive evidence of the fact that no sharp demarcation can be drawn between self hardening and high speed steel. It may be that as at present manufactured, the high speed steel differs materially in composition from Mushet self hardening steel. It may be that the proportion of tungsten has been increased and that of manganese lowered, or that in some brands the tungsten has been replaced by molybdenum. The fact remains, nevertheless, that to all tungsten steels of the self hardening variety, if properly treated, high speed qualities may be imparted. By altering the composition, as pointed out, these high speed qualities may be intensified, but the difference between the two varieties of steels remains at best one of degree, not of kind.

7 Again M. Le Chatelier in his paper "Les Aciers Rapides et Outils," speaking of the Taylor-White process, says:

> One has often heard that this discovery was simply a chance: a workman had by negligence heated to a high temperature a tool of Mushet steel, and contrary to what one would have believed, this abnormal treatment made it much better.

8 Here M. Le Chatelier makes it clear that the Taylor-White discovery was a *process* and not a new mixture. At the same time it should be clearly understood that the new high temperature hardening of the last few years for high speed steels has led to constant variations and improvements in the mixtures. Those who have carefully watched results, and followed up clues have made very considerable

progress,so that now high speed steel is made and used for a variety of tools, drills, milling cutters, etc.

9 The following instructions were issued and circulated by my company before the general introduction of high speed steels:

"To obtain improved feeds and speeds R. Mushet's special steel (self hardening) should be heated *gradually* but *thoroughly*, so as to be quite ductile. The tools should then be forged at a *good heat*. Avoid forging it too cold. When forged the cutting end of tool should be *reheated to a good scaling heat*, and then, if possible, *blown cold*. While hot this steel must be kept from water."

10 This circular merely reproduced in printed form the verbal instructions given for years previously by their experts, who visited the engineering shops, showing the smiths how to *heat-harden* and *air-cool* Mushet tools, so that there were few smiths that did not use this improved process. The issue of printed instructions was for a long time avoided, as such instructions would have fallen into the hands of imitators of Mushet steel, and thus given them the opportunity of bringing their products nearer in quality to the original. This point, namely, the leveling effect which heat treatment has on steels of different compositions, is emphasized by Mr. Taylor in his paper.

11 In nearly all recent trials of lathe tools, such as the Taylor-White tests published during the Paris Exhibition, and the Manchester trials of 1903, Mushet steel has been made the standard of comparison. As I pointed out at the Manchester discussion (see Transactions of the Manchester Association of Engineers, 1903, pp. 255, 338, 339, 340, 341, 345): "The treatment was as important as the composition of the steel." Subsequent developments have proved the truth of my contention, although at the time my critics maintained the fallacy that the heat hardening treatment of Mushet steel was a new idea.

12 The points on which I wish to lay emphasis are:

a That high speed steels are the natural outcome of Mushet's discovery known as "Mushet Steel."

b That previous to the Taylor-White process, Samuel Osborn & Company, the makers of Mushet steel, had recommended a high heat hardening treatment; and

c That Messrs. Taylor and White further improved on this heat treatment and made it widely known, the result being an epidemic of high speed steels.

13 For these reasons my company calls their present product *Mushet* High-Speed Steel, their contention being that it is *not* a new steel but the result of improvements on the original Mushet steel.

14 Referring to the system of lathe trials conducted by Mr. Taylor, it might be interesting to him to know that generally speaking the trials conducted at the works with which I am connected are on the same lines:

STANDARD SHAFTS FOR LATHE TRIALS

Taylor	*Osborn*
Steel (Carbon .35%)	Steel (Carbon .50%)
Steel (Carbon 1%)	Steel (Carbon 1%)
Hard Cast Iron	Hard Cast Iron

The feed and cut adopted have been the same, viz: $\frac{1}{16}$ inch by $\frac{3}{16}$ inch.

15 In conclusion, I should like to repeat a remark often made by my late father to Mr. Benjamin M. Jones of Boston, a personal friend and prominent man in the steel trade of the United States:

"Mr. Jones, it (referring to Mushet steel) is a sleeping giant, and will someday wake up."

Little did he realize how true his words were and what a vigorous share in the waking process would be taken by Messrs. Taylor and White.

MR. J. E. STEAD[1] Ever since the introduction of high speed cutting steel by Mr. Taylor and the method of treatment introduced by Messrs. Taylor and White, I have devoted much attention to the study of what composition of steel is best to give the most efficient all around result. It is, however, inexpedient for me to say more than that some of the steels which gave the best results contained between

0.6 and 1.0 Carbon
2.5 and 3.5 Chromium
11.0 and 18.0 Tungsten.

Some steels contained high percentages of silicon, the amount varying between 1.5 and 2.5 per cent and they gave very satisfactory results in the engineering shops.

2 The practical trials were all made under the direction and superintendence of Mr. John Key, of Messrs. Richardsons, Westgarth & Co., Engineers, Middlesborough, who has devoted much time and attention to ascertaining the performance of high speed steels when used under varying conditions. At my request Mr. Key kindly sent me the result of his experience, which is as follows:

The paper "On the Art of Cutting Metals," by Mr. F. W. Taylor, read before The American Society of Mechanical Engineers, is of a most comprehensive nature.

[1]Borough analyst, Middleborough, England.

Those who have attempted experiments on tool [illegible] classification can appreciate the labor and care required to produce the information in the form given.

Our experience with high speed tool steel and metal cutting confirms, so far as we have gone, many of Mr. Taylor's conclusions, notably the weakness of the feed mechanism of the ordinary lathe.

Some time ago a number of our old lathes were fitted with high speed heads with only slight modification to the feed gear, the result being, of course, disaster, and the design was altered as far as the arrangement of the lathe would permit but even now is not at all satisfactory.

When we commenced high speed cutting we considered it to be the proper thing to remove as heavy a weight of cuttings per minute as the tool and machine would permit, regardless of the power required. After a number of experiments it was found that beyond a certain weight of chips removed per minute, the consumption of current was excessive and did not compensate for the extra work done, therefore the cutting speed was reduced to that which was considered the economical limit.

A defect which has troubled us to a great extent in high speed work is that of the irregularity of the turned surface, necessitating several finishing cuts. The irregularity was caused through the vibration of the work and sometimes the result of the wearing of the centers with heavy pieces.

Although great progress has been made in roughing out wrought iron and steel bars and forgings, scarcely any improvement has been made in the time required for finishing in the lathe.

The author of the paper does not go into the matter of cutting metals on planing machines where the removal of the chips take place under different conditions from that of a cylindrical surface, as in a lathe.

In cutting cast iron in a planer we find a cutting speed of 50 feet per minute a fair average, similar material in a lathe being tooled without trouble at a speed of 120 feet per minute.

The planers are specially built for high speed work and have particulars as follows: 56″ x 12′ stroke cutting 50′ per minute and return 125′ per minute. 24′ x 6′ stroke cutting 50′ per minute and return 230′ per minute. The shock of return is taken by heavy spiral springs to which is attached the driving rack.

In conclusion I would like to express our indebtedness to Mr. Taylor in publishing freely the results of so many years investigation and which cannot fail to be of the utmost assistance to those of us who are interested in "The Art of Cutting Metals."

3 I most heartily endorse Mr. Key's praise of the most valuable of work Mr. Taylor. The engineering world in particular is greatly indebted to him.

Mr. Oberlin Smith I think we cannot fully appreciate, unless we have made comparative tests, the losses due to slow speeds in the old fashioned shops. As an instance; going through one of our largest shipbuilding concerns, I saw the rough job of drilling boiler heads for manhole contours going on at a rate of six feet cutting speed per minute all day long, simply because nobody paid any

attention to how fast the drill ought to run. We cannot attach too much importance to this new and grand era of reform, which means billions of dollars added to the wealth of the world, and which started with the incomparable work of Mr. Taylor and Mr. White.

2 In driving the new and extra powerful tools for using high-speed steels, much attention has been paid to trains of gearing and endless chains for getting sufficient torque, the poor old fashioned belt being neglected, as being too weak and of no account. The trouble with the old time belt drives has usually been because the belts have been run much too slow, hence not having the capacity to transmit much energy. We all know that we can run a belt up to a speed of about a mile a minute if we want to, although the best practice would probably be to keep down somewhere near 4000 feet. This, however, depends upon the weight of the belt, the size of the pulleys, and other conditions, the chief evil to avoid being that of centrifugal force carrying the belt somewhat away from the pulleys and lessening the contact pressure.

3 In equipping the new works of which the writer is the head, he had occasion to equip 100 or more machine tools of all kinds—and no two exactly alike—for individual electric drive, he having considered "group driving" one of the fossils of ancient history. In doing this he has used various methods, in some cases retaining the old cone pulleys self-contained upon the machine, and driving with constant speed motors. In many other cases, especially for lathes, he has depended entirely upon variable speed motors with field control and two wires. By changing somewhat the ratio of one pair of gears in the back gearing of a lathe and mounting upon the old spindle cone or cone sleeve a large gear with a new shaft in front containing a pinion to drive the same, he has found the cheapest and most practical method to be the driving of this small shaft direct from the motor, with a short belt, running upon as large pulleys as possible, to give it a high speed. This should be of the best possible quality of leather, quite thin, and made permanent with a cemented seam into an endless belt. It can afterward be tightened as it stretches by a slight adjustment of the motor upon its shelf—this shelf usually being a casting attached to the head of the lathe, several inches above the spindle. A little belt of this kind running at from 3000 to 4000 feet per minute will have an enormous amount of power, and can be kept so loose as not to be strained up to its usual working limit, thus being very durable. Furthermore, when running so loosely, the shafts are not pulled tightly toward each other (as in the old fashioned shop) with a consequent saving of loss of power and money by journal friction and wear.

4 Many modifications of the above arrangements can be made, suited to the particular machine which is being equipped. The principal idea to keep in mind, however, is that the belt must be strong, thin, and endless. There need not be any fear of its being too short by having the pulleys too near together, providing it runs at a very high speed.

MR. W. H. BLAUVELT Mr. Taylor states in his paper "On the Art of Cutting Metals," that he discovered during the past year that vanadium is a useful addition to high speed steels. (See p. 11, paragraph 50, and page 219, paragraphs 1088–1094). I think it will interest Mr. Taylor to know that Patent No. 779,171 was issued on January 3, 1905, to Mr. John A. Mathews for the use of vanadium in both molybdenum and tungsten steels of the high speed type. This patent was mentioned in the "Electro Chemical and Metallurgical Industry" in February, 1905, and also in the "Journal of the Society of Chemical Industry" of February 15, 1905. This patent was applied for some six months before its issue and the first experiments bearing on the subject were made in 1903.

2 I know that Mr. Taylor will be interested in the corroboration of his discovery by the results of earlier experience along the same line. This is manifestly one of the frequent cases of the discovery of the same idea by a number of independent workers along any line of investigation.

MR. DANIEL ADAMSON[1] By the courtesy of the author in sending me advance proofsheets with a request for some remarks in discussion I have been able to briefly review this paper. I am very glad of this opportunity as I was Honorary Secretary of the Manchester Committee which carried on the experiments frequently referred to by Mr. Taylor.

2 Paragraph 77 of the paper should be corrected. The Report of the Manchester Committee's trials was published by the Manchester Association of Engineers in their Transactions in 1903, whereas the paper referred to by Mr. Taylor and published in the Transactions of the American Society of Mechanical Engineers in 1904, Volume 25, was a later and individual effort on the part of Dr. Nicolson for which he alone was responsible.

3 Mr. Taylor in his paragraphs 79 to 82 criticises the method of procedure of the Manchester Committee in the light of his greater experience. I submit, however, that the Manchester Committee should not be judged in this manner, but rather from the point of view

[1]With Joseph Adamson and Company, Hyde, England.

of the general knowledge on the subject at the commencement of their experiments. The Manchester Committee had no previous experiments to guide them except the German results referred to by Mr. Taylor in paragraph 78 and which will be found carefully summarized in Appendix III of the Manchester Report.

4 The whole of the Manchester experiments were carried on by voluntary effort. The members of the Committee gave their services; the Municipal School of Technology provided the room, the power, and the clerical and technical assistance required for carrying out the trials and recording and elaborating the results; the eight firms concerned gave all the tools, and one of them gave also the material operated upon and loaned as large a lathe as the premises would admit; while the Manchester Association of Engineers bore the cost of publishing the Report and offering it to others outside their membership at a nominal price. The results were published immediately on completion for the benefit of the engineering world generally.

5 Mr. Taylor throughout his paper makes such generous reference to the Manchester trials, and the subsequent experiments by Dr. Nicolson on his own account, that I think he should in justice modify the deprecatory tone of his paragraphs 79 to 82.

6 Mr. Taylor criticises in paragraph 85 the suggestion from Manchester that the area of the cut can be considered as a single variable in its effect upon the cutting speed, and while I have no doubt that my friend Dr. Nicolson will take an opportunity of replying to the many criticisms upon our work in Mr. Taylor's paper that more directly concern his deductions, I must myself say something about this relation between the areas of the cut and the cutting speed attained as I find that during the discussion on the report at Manchester I made the following remarks:

> They had each had their own ideas as to the results to be shown by these experiments. I personally had been anxious to see some connection between the actual speed obtainable and the cross section of the cut being taken. This connection was shown by Plates 3 and 4. If they had a given class of work in their shops, and a given quality of iron castings or steel forgings, they could easily ascertain how much slower they would have to run if they increased the weight of their cuts, and quickly ascertain from the results now published the advantage of so doing if the work and the machine would stand the heavier cuts.

7 From Plates 3 and 4 in the Manchester Report referred to, it will be seen that on soft steel we obtained a speed of 54 feet per minute on a cut of .04 square inches area, a speed of about 78 feet per minute on a cut of .02 square inches area, a speed of about 112 feet per minute on a

cut of .01 square inches area and a speed of about 140 feet per minute on a cut of .005 square inches area. This curve was based upon cuts varying in ratio of depth to feed from 1 to 1 to 3 to 1, and it would be interesting if Mr. Taylor would tell us the amount of error entailed by our method when compared with his own, over the range mentioned in the Manchester Report. Judging from the author's Table No. 45, Folder 8, the divergence cannot have been great. See my diagram herewith which is self explanatory. It seems to me very unreasonable for Mr. Taylor to stretch an assumption, ostensibly based upon an extreme range of ratio of 3 to 1, by applying it to a case where the range is 16 to 1 as in his cuts of $\frac{1}{8}$ inch deep by $\frac{1}{8}$ inch feed compared with $\frac{1}{2}$ inch deep by $\frac{1}{32}$ inch feed in paragraph 85. No engineer reading our report for instruction, as distinguished from reading it for idle criticism, would be misled as suggested by Mr. Taylor.

8 There are a few differences in detail between Mr. Taylor's methods of carrying out these tests and those adopted by the Manchester Committee and I think it well to mention these, if only for the guidance of the future investigators Mr. Taylor refers to occasionally in his paper.

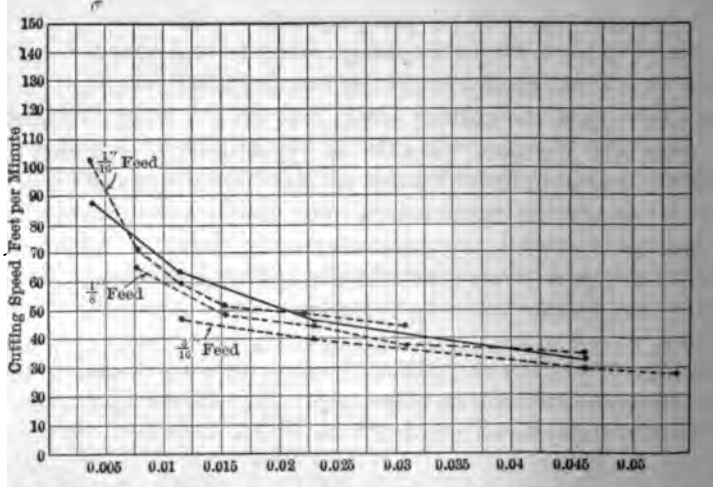


FIG. I DIAGRAM SHOWING COMPARATIVE RESULTS OF EXPERIMENTS BY THE MANCHESTER COMMITTEE AND BY F. W. TAYLOR

UNBROKEN LINE SHOWS RESULTS OF MANCHESTER COMMITTEE'S EXPERIMENTS ON STEEL CONTAINING 33 PER CENT OF CARBON. DOTTED LINES REPRESENT F. W. TAYLOR'S RESULTS ON STEEL CONTAINING 33 PER CENT OF CARBON.

9 We took the *mean of the diameters* before and after cutting when calculating our average cutting speeds. This is preferable to using a rotameter on the "larger of the two diameters of the forging" as

mentioned in paragraph 231. While I strongly recommend a "cut meter" for general shop use in checking speeds, the rotameter is absolutely unreliable for a "scientific" trial.

10 At Manchester we *weighed* the cuttings removed during each trial as a check upon the other measurements of cut, speed, time, etc. We kept a record of the longitudinal distance traveled by the tool during a trial merely as a check and we also noted the revolutions of the lathe spindle during each trial as shown by an automatic counter. This is much better than depending upon the rotameter as mentioned in paragraph 233.

11 The depth of cut applied at each trial was gaged by a graduated disc on the screw of the saddle, just in the manner in which cuts are applied in milling and gear-cutting machines, using the screw as a micrometer and adding an amount, previously ascertained as correct for the given cut, to compensate for the spring of the tool and rest.

12 This method is much more "scientific" than Mr. Taylor's, notwithstanding paragraph 241. In any case, I do *not* approve of the "cut gage" illustrated, as a handy tool to use on a forging in a lathe traveling at such a high speed that calipers cannot be used, see paragraph 238. We measured the bar at *several places* before and after the cut had been taken. We recorded the different diameters as mentioned in paragraph 241 just as we recorded many other points, for the same reason that public balance sheets are issued in financial affairs, that all concerned may see what has been done. It would have been interesting if Mr. Taylor had recorded *his* actual measurements in the same way.

13 Mr. Taylor's paper, voluminous as it is, is singularly deficient, for an engineering paper especially, in giving such records as will enable a careful reader to check the deductions arrived at. Throughout our records, particulars were given that would, we anticipated, enable future investigators to analyze our results and possibly draw fuller deductions from them than we did. There are many conclusions given in Mr. Taylor's paper as the result of his long continued experiments; but the grounds upon which they are based, or the methods by which they may be applied in practice are omitted. For example, I may refer particularly to paragraphs 279 to 288 and to the "conclusions" given in Table 45 and other similar tables. "To err is human" therefore readers should be given every opportunity of ascertaining for themselves whether there is any error in drawing the conclusions.

14 I must enter an objection to the suggestion in paragraph 415 that the trials held in Manchester were in any way a "competition."

The Manchester Committee looked upon their effort as a preliminary attempt to show what was possible with the then new steels and a beginning in investigations that would go on indefinitely, and it was in no sense a "competition" between the different makers as Mr. Taylor suggests.

15 Paragraph 426 contains advice as to the importance of lowering tool supports that I gladly endorse as I have kept this point in view for about ten years past, when buying lathes, in order to be able to use the "turned up" tools, but I am much surprised to read his criticism of American Machine Tool Builders in paragraph 583. This is not the impression one would gather from reading the American technical press, although it confirms a very general English opinion that the gearing, especially of American lathes, is too light.

16 Referring to paragraphs 35, 45, and 120, Mr. Taylor cannot be expected to know the shop practice of England, but one of my fellow members of the Manchester Committee assures me that he has known of a heavy stream of water being used on tools for the past 30 years without discovering so great an advantage as 40 per cent, and he suggests that 15 per cent as mentioned in paragraph 629 would be nearer the mark according to his own experience.

17 Mushet tools were freely used *long before* 1894–1895 for turning and planing large surfaces of cast iron that required to be completed at one setting of the tool, and the employment of special men to grind all the tools in a shop has been very common practice for at least the past twenty-five years.

18 A strong stream of water was used in my own works 20 years ago to enable the carbon steel drills of that period to get through hard iron castings.

19 In paragraphs 247, 473 and 1016, Mr. Taylor gives some valuable recommendations as to tool grinding, and I would like to ask him whether there are, in his opinion, any substantial grounds for a very common preference in England for the use of sandstone rather than emery wheels for tool grinding.

20 In paragraph 496, Mr. Taylor states that the side pressure on a tool is often equal to the downward pressure and yet in his special pleading for the rectangular section of tool in paragraphs 415 to 421 (as being preferable to the square section used in the Manchester experiments) he forgets this. If the two pressures are equal, then the square tool is evidently more nearly correct, if the reasoning illustrated in Figs. 14, 15, 16 on Folder 2 is to be relied upon.

21 In paragraphs 784 to 794, several constants are given for use in various formulæ for calculating cutting speeds for various sizes of

tools but these are apparently only for one quality of steel—medium—nor do I find in the paper any guidance for ascertaining similar constants for hard and soft steels. Is this in accordance with paragraph 131 which states that one of the principal objects of the paper is to make public the results of the experiments as embodied in laws, etc. And further, the very formulæ given are much too elaborate for use outside a mathematical class room.

22 There are a few points not referred to by Mr. Taylor regarding which I hope he will give some information from the stores of his long experience when replying to the discussion.

23 What is Mr. Taylor's opinion of tool-holder tools for turning and planing? In England, the use of high-speed steels has given a great impetus to the development of tool-holders in which a small piece of tool steel is held to do the cutting, the stresses being taken by the body of the holder. The advantages claimed are that the outlay for expensive tool steel is reduced, while the grinding and tempering is simplified and no forging is required. This elimination of *forging* is alone a most important feature, as may be judged by the large amount of attention Mr. Taylor has devoted to it in his paper.

24 Again, there is no reference in this paper to the height of the cutting edge in relation to the "centers" of the lathe. Does Mr. Taylor intend the tool always to be placed "on the center" or elsewhere? There is a strong opinion in England that the height of the tool in relation to the center of the work has a great influence upon "chatter."

25 Also Mr. Taylor makes no mention of the difference experienced between cutting "acid" and "basic" steel forgings *of the same chemical analyses*. I have reasons for believing that tnis is an important point and should be regarded as another "variable."

26 Again in paragraph 372 Mr. Taylor speaks as though dead soft steel were something comparable with "wrought iron." This is not correct from a machinist's point of view. Wrought iron is much more troublesome to cut than steel.

27 Mr. Taylor makes no reference to the effect on cutting speed of the "skin" on the outside of forgings and castings that must be negotiated by the tool on the first cut, nor to the very hard spots that occur in machining large steel castings.

28 In conclusion, if my remarks seem rather disjointed, this must be put down to the voluminous character of the paper, and also to the great amount of repetition. This repetition and some apparent contradictions make it appear as though the task of properly recording his work had been too great even for the tireless activity of the author

and it does appear as if the paper would be enhanced in value by a careful editing and some reduction of its bulk. As an example of what I here refer to, please turn to paragraphs 35, 593, 594, 598 and 624 and the heading preceding paragraph 610, all of which repeat almost *ad nauseam* the statement as to a 40 per cent gain in speed by using a heavy stream of water on the tool, only to have the same contradicted, or at least reduced to 15 per cent in paragraphs 628 and 629. Paragraphs 674 and 675 are apparently mere repetitions, the one of the other. Also the large type following paragraphs 680 and 709. Also paragraphs 546 and 565. Also paragraphs 555 and 589. And there are many other examples throughout the paper.

29 Compare also paragraph 505 and paragraph 519 as to relation between cutting speed and tensile strength, these seem to contradict each other. Paragraphs 44 and 729 are very confusing. Paragraphs 1194 mentioning the author's failure to carry out his intention of explaining the best method of procedure in incorporating the various laws upon the latest type of slide rule is very disappointing to read after paragraph 51 had enlarged upon the great value of this part of the work and there does not seem to be any advantage in publishing it (paragraph 1194).

30 As an example of what might be done to simplify the paper, I would suggest the omission of the repeated references to the superlative merits of a trial run of 20 minutes duration in paragraphs 64 to 71, 137 and 703 and retain only the plain straight-forward statement in paragraph 183.

MR. W. S. HUSON This address and the discussion are of great value to those of us interested in rapid production. It seems to me, however, that the paper does not touch sufficiently on what to many of us, interested in comparatively lighter manufactures, is a vital factor in production; that is, the accuracy of the work when machined. Take as an instance a printing press type bed, a rectangular hollow or ribbed casting three or four inches thick and say four by six feet area of surface. When planed this piece should be within a thousandth of an inch, by test, by the straight edge. When planed at high speed the work heats and the dulled cutting edge tends to lift the stock and plane out hollow portions in the surface. While the piece undoubtedly leaves the planer quicker than with slower speed and carbon tool, when the manual labor and the time taken to file or otherwise dress the surface to the required accuracy, are added to the cost, nothing is gained and the hand labor is lost for some other work where it could be used to better advantage.

2 The same feature applies to milling; the high speed cutters seem to peen the work so that within a short time after being removed from the miller, it has changed from its orginial condition to the extent that slower speeds and the sharper carbon cutters give better results at a less final cost.

3 It is often the case that a manager will dwell on the speed with which he can do certain operations and overlook the charge for the cost of afterwork which could be avoided by slower speed at the start. High speed steel has been a revelation as to what can be done in rough reduction of stock, but I do not consider carbon steel a back number. It has its field and undoubtedly the advent of high speed steel has brought out qualities in the carbon to which little or no attention had previously been given.

4 As to Mr. Hawkins' remarks on the all around man, he is going out of use because he does not fit in the modern shop. The same applies to the so-called all around tools of the past. To day, it is a gear cutter for cutting teeth, a miller for milling, etc. The mission of the all around man is done. The anchor must be of known quantity to the skipper, the fiddle true to the master's touch, and each should be made by him skilled in its making.

MR. C. CODRON[1] We have read with the greatest interest Mr. Taylor's paper, describing his remarkable investigations on the art of cutting metals. There can be nothing but praise for this work, which records the results of an enormous number of experiments, involving an expenditure of time, money, and talent which has no equal in the annals of experimental investigation. It is not possible for us to comment hastily on a work of such importance. I can, nevertheless, say that Mr. Taylor has investigated the subject of turning metals from all practical points of view, in a most careful and thorough manner. He has brought together the tests of Sellers and Nicolson, arranging them for comparison with his own, neatly and precisely, in tabular form, so that many points are cleared up which heretofore have not been well understood. It seems that no element connected with cutting metals in a lathe had been neglected by him.

2 Although he limits his investigations to the turning tool, he shows by the great extent of his work, by the various elements to which he calls attention, and by the interesting discussion which they bring forth, the great complexity which a simple cutting tool presents when working upon iron and steel. He shows likewise all the difficulties involved in carrying out comparative tests in this field when

[1] Professor, Technical Institute of the North, Lille, France.

endeavoring to make them, first under uniform conditions and then under varied conditions.

3 Those who are not familiar with work of this nature must be greatly surprised that a subject apparently so small is capable of such great development. We must congratulate Mr. Taylor on having included in his paper so many wise conclusions and comments, showing wonderful ability as a trained and accurate observer.

4 We will make only one remark, which relates to diagram on Folder 12, Figs. 82 and 86.

According to the tests of Mr. Nicolson, the pressure on the tool decreases when the speed increases. At first very rapidly, then very slowly.

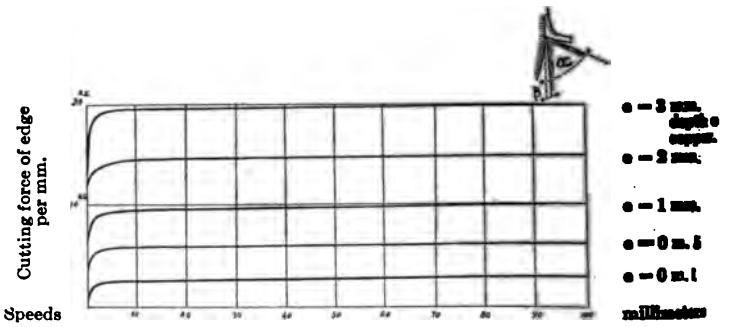


FIG. 1 CUTTING LEAD AT A VARIABLE SPEED, $\alpha = 75°$, $\beta = 5°$

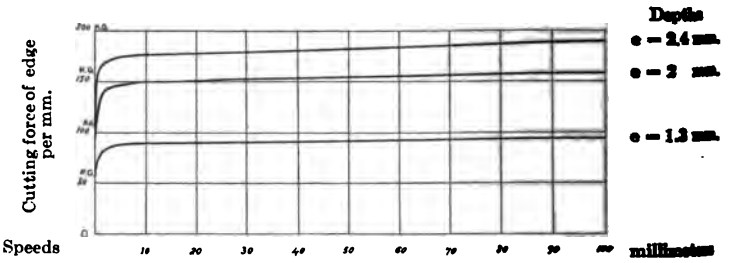


FIG. 2 CUTTING COPPER AT A VARIABLE SPEED, $\alpha = 45°$, $\beta = 5°$

Now, our experiments with cutting tools have led us to the opposite conclusion, and we have also reached a similar conclusion for punching and drilling.

5 We maintain *a priori* that the same law exists for all different metals; if, for example, we experiment in cutting a metal which is very soft and very ductile, such for instance as lead, in a metal cutting machine which allows us to use very low speeds, say only a few millimeters in several hours, we find a law clearly indicating that the pressure increases rather rapidly with an increase of speed at very slow

speeds, and that it then tends to remain constant or to rise little. With hard metals, such as iron, we have been unable to deduce any law, because the cutting tool causes the chip to break off suddenly, and consequently great variations in the pressure are recorded. In cutting hard steels, also, the chip is broken up into sections, thus producing great variations in the pressure. This, by the way, is also shown in Folder 12, Figs. 82 and 86, of Mr. Taylor's paper.

6 Since the speed in turning metals of this character is always relatively high, we can therefore neglect the slight effect which the speed has upon the pressure at ordinary speeds. We have arrived at similar conclusions in our experiments in shearing, punching, and drilling metals.

7 We state with pleasure that the curves which Mr. Taylor shows as representing the average of his many experiments agree in their general outline with those of our tests, which we have not yet published, and which refer to cutting tools in general.

8 We are sorry that we cannot speak more at length of the paper. Mr. Taylor has had the kindness to highly praise our experiments on drilling; for this we thank him most cordially.

9 The two accompanying diagrams represent the varying pressures on a lathe tool in cutting lead and copper at varying speeds, and with various thicknesses of shaving.

MR. WILFRED LEWIS I have read with much interest Mr. Taylor's address "On the Art of Cutting Metals," and wish to express my appreciation, not only of its great scientific value, but also of its far reaching importance to the metal industries of the whole world; and I venture to predict that as time goes on, this art, which Mr. Taylor more than any one else has helped to put upon a scientific basis, will grow vigorously, resting upon the solid foundation he has laid.

2 Hitherto the fundamental questions as to cutting tool, speed, and feed have been left to the judgment of the mechanics or handymen running machines, and the employer of labor has been practically adrift at sea, but with the knowledge of what Mr. Taylor and his associates have done before him, he is now in a position to demand a return in product commensurate with his facilities for production, and to offer a liberal compensation to labor for the performance of the task assigned to it. He is no longer obliged to feel his way in the dark, and accept with thanks the crumbs of comfort that may come to him as the result of tempting offers to increase production, not knowing what should or should not be expected in any case. But overwhelming as this paper is in the mass of detail covered, and the

labor involved in the fruitful generalizations therefrom, the important fact should not be overlooked that it is only a part, and a comparatively small part, of a much larger subject which was presented to this Society by Mr. Taylor more than three years ago.

3 It has been my good fortune to have had some experience with the Taylor system of shop management, as outlined in that paper, and I believe it is only through this system of mechanical management that the full benefits of his work "On the Art of Cutting Metals" can be realized.

4 The success of this system is made to depend upon the success of all concerned, and the benefits of increased production are shared by the men who contribute to them in following explicit instructions, as well as the leaders who fix the tasks to be performed. Obviously, the larger the plant the greater the need of organization, and the larger the results to be expected from any system of management; so, having but a small plant, with only 140 employees, including office, business, and selling force, I was at first in doubt as to whether the Taylor system could be established successfully.

5 As with any new piece of machinery, the expense of installation is a heavy burden until it begins to pay, and for the first two years progress was impeded and almost stopped by the obstructionists who knew "something better," but during the last year, the intrinsic merit in the system has told plainly in the results produced, and with a slight reduction in the number of our machinists and a large increase in our managing force, resulting in a total working force of about 160 men, as against the former force of 140 men, we have more than doubled the production of the previous year and converted a loss of 20 per cent on the smaller volume of business into a gain of 20 per cent on the larger volume. At the same time, our working force has become united, contented, and happy in the better wages which we have been able to pay for strict attention to duty and satisfactory performance of the allotted tasks. Better times, better sales, and the marketing of superior products have also helped to bring about better results, but the increased capacity of our plant under the Taylor system of management is the important fact to be noted. This has been doubled and may possibly be doubled again as the system now established becomes more perfectly adapted to our needs. Its general principles are not affected by the character of the business to which they may be applied, but in introducing the system, the concrete forms in which those principles are cast demand the constant attention and skill of an expert in their preparation.

6 I would, therefore, call particular attention to the fact that it

is not desirable and hardly ever even practicable for the managers of a company to introduce the Taylor system themselves; that is, to undertake its introduction without the help of men who have been especially trained to this work. It is exceedingly difficult for anyone who has not had personal experience in meeting and overcoming the obstacles that are sure to be encountered, to introduce it and avoid, while so doing, the danger of strikes, and also of possible deterioration in the quality and quantity of the output of the shop.

7 During the period of introduction of the Taylor system, the entire attention of the management is especially needed in the actual daily running of the works and business and, as Mr. Taylor has said in his paper, "Any company is indeed fortunate which can secure the services of a man who is competent to introduce it." I feel that the Tabor Manufacturing Company has been especially fortunate in this particular, and that our successful introduction of the Taylor system would still be in the dim and distant future, had we not secured very early in this work the services of a competent expert like Mr. Barth, and also, particularly, his assistant, Mr. H. K. Hathaway, who stood by us and helped us through a very trying and disheartening period of development. Now that we are fairly on our feet and beginning to run along without Mr. Hathaway's assistance, we realize that when once introduced, it is far easier to run our works on the Taylor system than by any other system of management.

8 It is not possible to present an adequate discussion of Mr. Taylor's paper "On the Art of Cutting Metals" at this time. Not for some years perhaps will its real value be understood and appreciated, and back of it all will then begin to grow the larger subject of which it is only a part, the labor problem reduced to its simplest terms by unlimited production and corresponding remuneration for the men who want to work hard and get paid for what they do.

Mr. R. A. Skeggs[1] Owing to the limited time before the meeting we have been unable to go very thoroughly into Mr. Taylor's work "On the Art of Cutting Metals." We can, however, say that the conclusions arrived at by Mr. Taylor confirm generally our own experiments and experience.

Taking them up by paragraphs:

2 (Par. 83.) The speed given for $\frac{1}{8}''$ cut x $\frac{1}{8}''$ feed is 10 feet per minute and that for $\frac{1}{2}''$ cut x $\frac{1}{32}''$ feed is $16\frac{1}{2}$ feet. We contend that, provided the work was rigid, if the tool were ground in such a manner as to cut off chips exactly similar in form, the speed would be the same in both cases.

[1] Vickers, Sons and Maxim, Sheffield, England.

3 (Par. 148.) We have frequently observed that tools will cool down and appear to cut with greater ease after running for some considerable time. We have accounted for this by: (*a*) A change in the hardness of material. In some cases forgings have been unevenly chilled to such an extent that the cuttings from one side have come off blue, while from the other side they have been almost colorless. (*b*) The tool lip surface becoming worn in such a manner as to give less resistance to the chip and consequently less friction. (*c*) It has been observed that a tool, running on an annealed forging of regular toughness so far as can be detected, which has been removing blue chips will cut off chips of a lighter color as the diameter is reduced, the speed of course remaining constant.

DIAMETER

4 Our experience is that the standard speed varies with the diameter. For example the standard speed would be higher for a 6 inch diameter than it would be for a 12 inch diameter, and it would be interesting to know whether Mr. Taylor has made any experiments in this direction. We suggest that the reason for this is that the material on large diameters approaches the tool at a steeper vertical angle, the chip having more support behind it, so that with very large diameters the conditions of cutting more nearly approach that obtained with planing. There does not appear to be any reference to the height of the tool with relation to the axis of the work, whether the cutting edge is on or above the center, or the relation of the tool angles to the diameter when making experimental tests.

5 (Par. 352 B.) The section of roughing tools is given as depth $1\frac{1}{2}$ times width. If, as stated in 509, the feed gear should give a pressure at the cutting edge equal to the pressure of the chip on the lip surface of the tool, should not the section of tool be square? Our experience in machining heavy forgings has led us to use a coarse feed and a square tool.

6 (Par. 585.) Chatter of the tool necessitates cutting speeds from 10 to 15 feet per minute slower than those taken without chatter. Has Mr. Taylor any formulae for obtaining working speeds when scale, uneven hardness, and very occasionally sand are to be met with in the forging?

7 Our experiments confirm generally the conclusions derived from the use of alloys which are dealt with under the heading of "Chemical Composition and Heat Treatment of Tool Steel."

DR. J. T. NICOLSON[1] I was pleased to receive by the courtesy of the author, an advance copy of the Presidential Address to this Society on the art of cutting metals; as also a request both from the Secretary and him personally for a contribution to its discussion. It proved a formidable task to read and digest even those parts of the paper in which I was personally more interested; and the portions referring to the composition and heat treatment of the steel I have had to pass altogether by.

2 I must preface my remarks by thanking the author for the gift of the great amount of information contained in his paper. I think all engineers and especially those concerned with the practical side of the art of cutting metals owe a debt of gratitude to Mr. Taylor and the men associated with him, for the pioneer discoveries they have made in connection with tool steel.

3 In reading this paper, which gives an account of these discoveries, as well as of other work in this art, one receives the impression of long continued and well-directed effort pursued with one main purpose. This purpose I take to be *the examination of the various elements which contribute to economy in the rough-cutting of steel and cast iron;* in the process, *i. e.*, of reducing the sizes of forgings and castings from the rough state to that on which the finishing cuts can be taken. The importance of such examination is evident, if as appears to be the case, it be more economical to forge roughly and turn off the excess, rather than to forge so closely to size as to require only a finishing cut. These elements may, broadly stated, be set down as three in number:

a The cutting power of the tool steel as dependent on its own nature;

b The cutting power as dependent on how the tool is used; as, *e. g.*, whether with a high cutting speed and light cut, or with a lower cutting speed with a heavy cut; whether with a keen or a blunt angle and a rounded or straight contour of the cutting edge; and as to what proportion the time spent in actual cutting should bear to the time required for grinding and dressing the tool.

c The improvement of the machine tool; so that, for example, its driving and transmission mechanism shall be so designed and constructed as to waste the smallest proportion of the mechanical energy supplied, and the minimum fraction of the machinist's time.

4 As regards *a*; the whole world is agreed as to the enormous

[1]Professor of Engineering, Municipal School of Technology, Manchester, England.

advances the introduction of the Taylor-White heat treatment of steels of a certain composition has effected in the art of cutting metals.

5 As to the above described element *b*, I am by no means disposed to concede all the credit which the author, in various parts of the paper, appears to claim, in reference to improvements in the mode of using the high heat steel of which he speaks.

6 And as to element *c*, in regard to which a knowledge of the laws of the cutting pressures are of at least equal importance to that of the laws of tool durability, although the author appears himself to have spent a great deal of time on the matter, it must have been quite without the consent of his better judgment; for in Par. 489 he writes: "Our principal object in writing at such length on this subject (*i. e.*, pressure on the chip) has been to endeavor to make it clear that . . . . a study of this element in the art of cutting metals is comparatively barren of practical results."

7 Descending from the general to the particular; there are a number of statements made by the author in Part 1 (which I take to be a summary of the whole) to which I strongly object; but I think they can be better disposed of by dealing with the more detailed remarks of Parts 2 and 3.

8 In Part 2 there is much matter in my opinion requiring either revision or exclusion; and there are several statements likely to mislead the uninitiated. In respect of personal matters, it appears to me that, notwithstanding the not infrequent words of appreciation and even of approval by the author of the work of other experimenters, the impression produced upon the mind of even the careful student, and much more on that of the cursory reader, will be that the Manchester experimenters, and especially the present writer, have fallen into lamentable and appalling blunders, which have led them to results entirely at variance with those obtained by the more careful and scientific methods of the author.

9 As an example I may cite Sec. 291 in which the author emphasizes most strongly that the most important subject for experiment in this art is the effect upon the cutting speed of *the thickness of the shaving;* and that it is more important to consider this than the area of the cut as a whole, in determining the proper cutting speed of the tool. He goes so far as to say (Part 1, Par. 85) that a formula for the cutting speed *based only upon the area of the cut* is wrong and misleading and that such a formula established on this basis by the Manchester Committee is *valueless* from a scientific standpoint.

10 Now what are the facts? A careful study of the author's

esults as given in his Tables 45, Folder 8 and 76, Folder 11 (which ables he cites as examples of the most successful series of experiients he has made) leads to the conclusion that, so far from revealng a glaring discrepancy from the law of cutting speed and area, nunciated by the Manchester Committee, the author's results (so ar as he publishes them) *do not differ from that law by more than 1 or per cent on the average* throughout the range of depths of cut and idths of feed ordinarily used for roughing out. The author has iven no experimental figures either in Tables 45, 76 or elsewhere substantiate the statement made in Sec. 281 C that the cutting

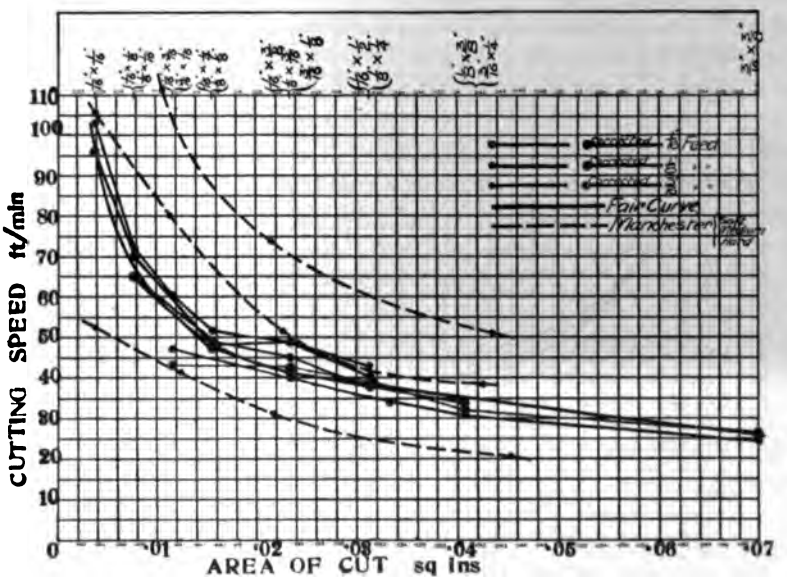


FIG. 1 RESULTS FROM TABLE 70, STEEL

peed may be 3½ times as great when the shaving is $\frac{1}{64}$ of an inch thick s it is when the shaving is $\frac{3}{16}$ of an inch thick. The finest feed in able 70 is $\frac{1}{16}$ of an inch. To elucidate the matter I have prepared vo wall diagrams, Figs. 1 and 2, from Mr. Taylor's Tables 45 and 76. I ave plotted the "standard" cutting speeds as given by the author nd their corrected values as they should, in my opinion, be taken om Mr. Taylor's own results) upon a base of area of cut; one curve r each width of feed.

11 I have then drawn a fair curve through all the spots on the agram. An inspection of the way the author's results lie about and

around this curve gives good ground for saying that Mr. Taylor's figures substantiate in a remarkable manner the fundamental law that the standard cutting speed with high heat steel for a given material depends only upon the area of the cut and hardly at all upon the depth of that cut or the width of feed. The author has tabulated no results which show a serious divergence from this law; and until he produces something tangible in this direction the statement he has made in Sec. 281 C must be characterized as entirely misleading.

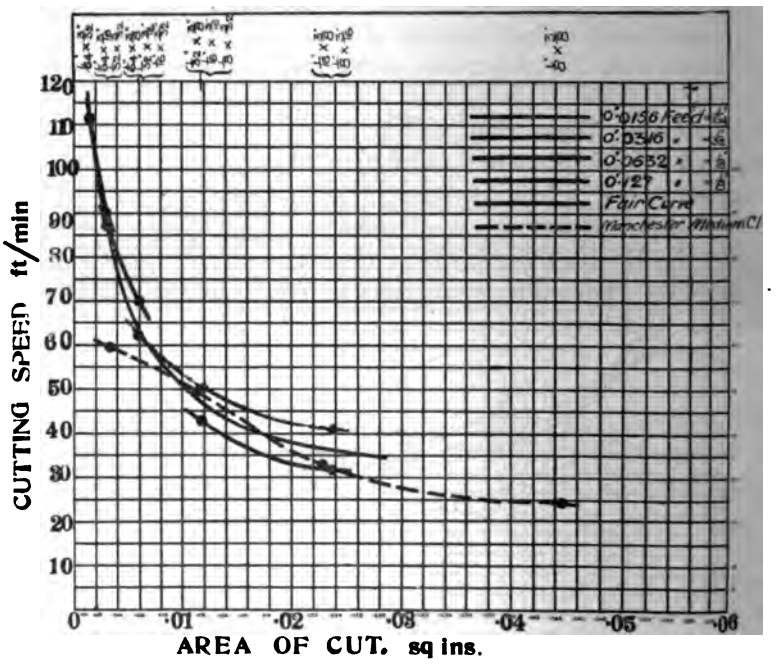


FIG. 2 RESULTS FROM TABLE 76, CAST IRON

ing. If the author had plotted his results on a base of areas, instead of as contour lines of constant feed upon a base of depth of cut, he might not have been led to make statements of this kind, so patently contradicted by the figures he himself gives.

12 As a matter of fact, a simple formula of the form

$$V = \frac{K}{A + Bc^n}$$

can be obtained to cover, not only the Manchester and Berlin, but also Mr. Taylor's results; with a divergence of only ± 5 per cent.

13 This formula involves only the area a of the cut in square inches, the amount of carbon c in the steel forging expressed as a percentage, and the constants K (depending on the tool steel), B and ^{n} (depending on the other chemical constitutents of the bar); *and makes no reference to either the thickness of shaving or depth of cut.*

14 It may not perhaps possess the accuracy of the author's formula in representing his own results (*vide* Par. 770), of this I have made no trial; but I have hopes of its greater practical usefulness as involving eight fewer constants, and only one variable for a given material.

15 If the author is in possession of experimentally obtained figures, proving that there is a considerable divergence from the speed on area law for such fine feeds as $\frac{1}{32}$ and $\frac{1}{64}$ of an inch, it may still be pointed out that he has himself expressly characterized (*vide* Sec. 252) such light cuts as *worthless* for the determination of the laws of cutting speed.

16 I am prepared to go a step further even than this; upon re-examination of the author's paper in its final form, so far at least as refers to the effect of the thickness of the shaving on the cutting speed (see Par. 291 to 306).

17 In Par. 297, the author gives the formula

$$\frac{V=1.54}{t^{\frac{1}{4}}}$$

for the standard speed of cutting (V), as dependent upon the thickness of the shaving (t). It appears, however (*vide* Folder 16), that the shavings in the experiments, upon which this law is based were all 1 inch wide.

18 The thickness of the shaving in inches is therefore the same as its area in square inches; so that the above formula might as correctly have been written

$$\frac{V=1.54}{a^{\frac{1}{4}}}$$

where a is the area of the shaving or the product of its breadth by its thickness. We have, therefore, no evidence from these experiments that the increase of the cutting speed as the shaving got thinner was due to the thinning.

19 It may just as logically be said that it was due to the diminution of the area. Similar remarks apply to the formula of Par. 302 in which, with equal propriety, the area might have been substituted for the length of the shaving.

20 In Par. 305 the author seeks to draw the inference that a shaving 1 inch wide by 0.01 inch thick would allow of a cutting speed (1.8 divided by 1.27 =) 1.42 times as great as a shaving of ½ inch and a thickness of 0.03 of an inch. This may hold for carbon steel tools although the conclusion is not to be clearly drawn from the author's experiments even for these. *The wide difference in the chemical composition of the bars used* for the two sets of experiments (Fig. 111, Folder 16, and Fig. 116, Folder 17) renders it futile to deduce the correct value of the effect of proportion of width to thickness in altering the cutting speed for cuts of the same area. The author here in fact commits a breach of his own laws of experimenting.

21 The author adduces no experimental evidence that any similar law holds for *high speed steel tools.* The very different ways in which the carbon steel tool and the high heat steel tool fail, render it extremely unlikely that the standard cutting speeds for shavings of different shapes will vary according to the same laws for both brands.

22 I do not deny that there is a difference in favor of the wide thin shaving when the feed is so fine as to be of the order of 1/100 inch, but I claim that the Manchester Committee's law that the cutting speed depends on the area alone is as a first approximation, true over the whole range of cuts and feeds which are usual in practice, and that its superior simplicity makes it a more generally serviceable rule for the practical man.

23 As another example of the author's method of combining unstinted praise with unsparing condemnation of the work of others, we may refer to Secs. 82 and 83 of Part 1, where, although expressing himself as satisfied that the Manchester Committee's results are of very great practical value, he yet states they were "carried on in a thoroughly unscientific manner."

Mr. Taylor says these experiments were defective because:

a The shape and cutting angles of the tools varied.
b The quality of the tool steel varied.
c The treatment of the tool varied.
d The depth of the cut varied from that aimed at.
e The experiments were not extensive enough.
f The uniformity of the bars from the center to circumference was doubtful.

24 The unsubstantial nature of these serious criticisms will, however, appear upon a closer examination; taking the objections in numerical order:

a It is true that the shapes of the various tools supplied was different for each maker; but with one exception they were all round nosed tools and the difference in the resulting law of cutting speed could therefore not be very great. As to the "lip angles" which varied in the Manchester experiments from 66 to 85 degrees the author himself states (Sec. 265), that the lip angle of the tool, if it exceeds 68 degrees, "makes little if any difference in the cutting speed, when cutting medium hard steels." This fact the author states he has found to be proved by repeated experiments made by himself.

b and *c* Undoubtedly the quality and treatment of the steel supplied by the different makers varied.

25 The object of the Manchester Committee was, however, to ascertain the then existent state of the art as exemplified by a selection of the best known brands of British (and one German) steel. But it appears to me that the author's objection to the Manchester experiments on this ground is nullified by the fact that (v. Manch. Rep. Plates 3 and 4) the cutting speeds as deduced from the mean of all non-failing tools (in 20 minutes) so nearly agree with those obtained from the best in each group. For the purpose of determining "standard cutting speeds" as understood by the author, the various steels used may be regarded as of one uniform brand.

26 *d*, *e* and *f* These objections are also either negatived or answered by a careful study of the Manchester Report, if at the same time the objects aimed at, as well as the methods employed to obtain them, are kept in view.

27 The most complete answer to these criticisms of the author is, however, the fact that the results obtained in Manchester by these alleged unscientific methods, fall absolutely into line with his own, when due allowance is made for the different carbon contents of the British and American bars. This is clear from an inspection of diagrams 1 and 2, and affords indeed, to me at least, one of the best evidences that Mr. Taylor's experiments were carefully made and worthy of general acceptation.

28 The author lays great stress (*vide* Part 1, Secs. 63 and 64, and Part 2, Secs. 144-149) upon his method of determining the variation of the cutting speed as depending upon shape and angle of tool and shape of cut by the adoption of the 20 minute standard; and seeks to imply that no other experimenters have used it.

29 Now this is the very standard arrived at by the Manchester

Committee without any knowledge of Mr. Taylor's work, at that time unpublished.

30 The credit for the fixing of this standard by the Manchester Committee is entirely due to one of its members, Mr. Daniel Adamson. After carefully studying the question, and looking into all the elements of the problem, such as material available, time at disposal, probable cutting speeds, and average durability of tools, he recommended the 20 minute limit to the Committee.

31 It was adopted by them at their meeting on April 21, 1902, and issued in their schedule of Conditions to the Steel Makers on April 23, 1902 (*vide* Manchester Report, p. 232).

32 In view of this fact, the remark made by the author (in Sec. 144) that the accuracy and delicacy of this standard had been but vaguely recognized, would appear to require revision. With regard to my own subsequent experiments on the durability of the tool, as depending on the lip angle, which Mr. Taylor properly, if somewhat severely criticises (Secs. 116 and 117 of Part 2), I beg to be allowed to insert the following quotations from my paper on the lathe tool dynamometer; from which it will be apparent that however much I might have wished to continue the application of Mr. Daniel Adamson's 20-minute standard, it was impossible for me to contemplate doing so, with only the remnants of the Manchester Committee's bars at my disposal for this purpose.

[Extract A from "The Engineer," April 14, 1905]

FORMATION OF CHIP

In order to observe at leisure the action of chip formation, it was arranged to take a cut at a very slow speed. The lathe was driven by taking several turns of a wire rope round one of the cone pulleys and then leading it to a hand winch. When the laborer turned the winch handle at ordinary speed, the cutting speed would be 1 foot in from one to five hours, according to the number of back gears in use. Lines having been ruled on the uncut surfaces of the work, forming squares of $\frac{1}{10}$ inch side, the distortion of these squares during and after the cut could be easily studied.

A chip formed by taking a cut $\frac{1}{8}$ inch deep from a collar $\frac{1}{4}$ inch wide, with a tool square-nosed in plan and having a 60 degree cutting angle, is depicted in Fig. 1. The originally circumferential and radial scribed lines are also seen, and the forms these lines take in a medium hard steel chip have been drawn to a scale about seven times full size.

At such dead-slow speeds the shaving breaks off in a succession of chips, which do not at all adhere to each other, by shearing off at an inclination of about 15 degrees to the vertical along *A B* or *A*1 *B*1. This angle does not vary with the angle of the tool, but the angle *B*1 *A*1 *C* of the chip becomes greater or smaller according as the tool is keener or more obtuse. The line *AB* shows where a chip

has just been shorn off and has dropped away; and the tool is seen beginning to act upon the wedge-shaped portion $AB\,A1$. However sharp the tool may be, its edge is still somewhat rounded; and it is, therefore, difficult for it at first to get below the surface of the work. Thus we find that the "surfacing" force—or the horizontal force pushing the tool forward square to the lathe bed—is greater

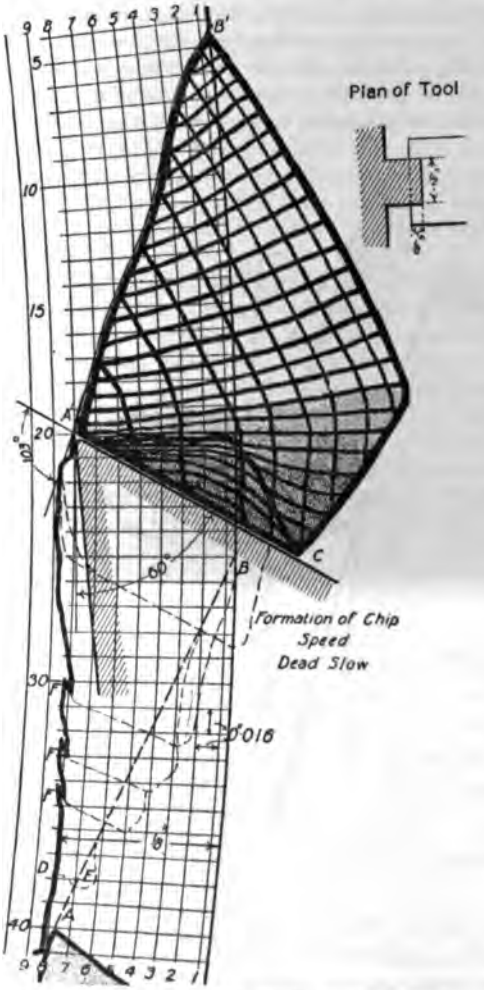


FIG. 1 FORMATION OF CHIP, SLOW SPEED

at this time than at any other, although the vertical force is then least, as the last chip has just been cleared off. If the surface of the bar is examined afterward, it is found to have a burnished appearance, just at this part, AD, where the tool pressed hard upon it. Once the tool enters below the surface it crushes up the material in front of it, and this is caused to flow outwards both along and

across the tool surface, as at *DE*. Slipping of this ma[illegible]n takes place over the tool and away from the work; but this slipping is not continuous, taking place intermittently and at longer intervals the more the tool cuts into the wedge *A B A*1. Each slip is accompanied by a small tear or crack running in front of the cutting edge, as seen at *F*; but these cracks extend for but a short distance at first, being healed up by the radial compression produced by the friction of the crushed material on the top of the tool when it comes to rest after having made a "slip." The same action is seen in the crushing of a short ductile specimen in the testing machine; the friction between test piece and platen being powerful enough to prevent cross-extension, uniform throughout its length, from taking place; so giving the crushed piece the barreled shape commonly observed.

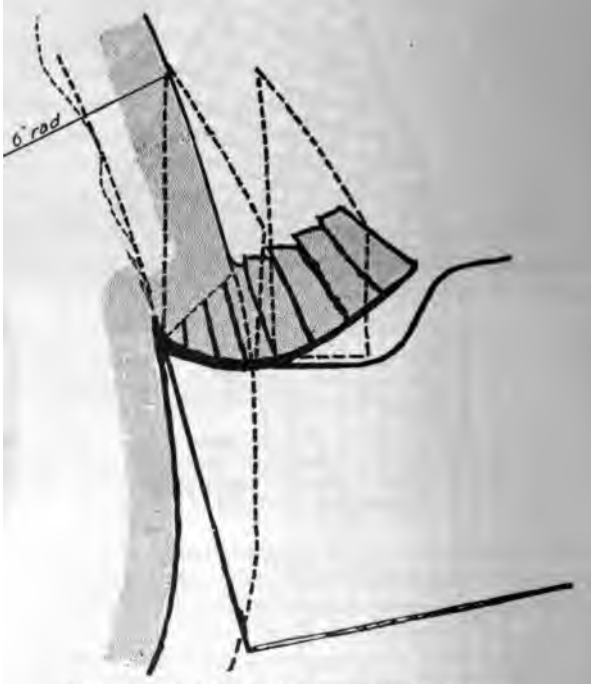


FIG. 2 FORMATION OF CHIP, HIGH SPEED

These little cracks—*FF*—run deeper, although at longer intervals, as the crushed material spreads further back over the top of the tool, and the consequent "slips" become more violent, until one such tear or crack extends right up to *A*1, and so out by *A*1 *B*1, and the chip drops.

The action at high speed is in many respects quite different from what takes place at "dead slow." The successive main shears—or rather, slides—of the shaving take place at shorter space intervals, for the slipping of the shaving over the tool now takes place continuously, and the cracks are no longer healed up by compression. The tear from one of the early cracks is now continued right out to the surface of the shaving. The progression of this tear across the shaving

is not instantaneous, however, and by the time it has reached the upper surface the chip has advanced some distance from the point of the tool.

If we now refer to Fig. 2, which shows how the shaving is formed at high speed, we see that this region of maximum stress extends from near the point to a considerable distance backward on the surface of the tool. The tear at the very point keeps running ahead of the tool, and is due not to the direct action of that point, but to the twisting of the material from behind the point where the pressure on the tool is greatest. In fact, the point itself is protected from all action of the work upon it by a small heap of the cut material being collected in the little space opened out by the advancing tear, and resting on a shelf of uninjured tool surface extending from the very edge of the tool to a greater or less distance back therefrom. This heap is firmly adherent, as to its base, to the shelf, but as to its upper part, is continually being removed and replenished from material left on the surface of the bar by the irregularity of the advancing tear. The nose of the tool sustaining the heap only cleans up the shaft, but does not cut the main body of the material from it.

The shaving, at that part of it where the crack is just running across, presses hard, as we have seen above, upon the top of the tool, and by reason of the speed with which it runs over the surface and the high temperature which it imparts to it, gradually wears a groove therein. This grooving starts at some distance back from the cutting edge and gradually advances by wearing away the shelf of unworn tool and diminishing the size of the heap, until, when the groove reaches the cutting edge and the shelf is all gone the tool "fails." Failure is the process—which occurs almost instantaneously, after the groove intersects the nose of the tool and produces a feather-edge there—of blunting and destroying this edge, the depth of cut then dropping considerably from its proper value. The "work of bluntness" is thereby largely increased, generates a correspondingly larger amount of heat right at the edge of the tool, and the cutting power is immediately destroyed.

33 I will only say, without defending the durability standard I was forced to accept, that the lip angles I recommended for shop use were 75 degrees for medium cast iron and 65 degrees for medium hard steel; while Mr. Taylor's results give a lip angle of from 76 degrees at the front to 68 degrees at the side, for the same materials (Sec. 342 A).

34 There are many other debatable points, I should desire to take up if time permitted.

35 With reference to Mr. Taylor's remarks on the interaction of tool and chip which take up his Par. 153 to 169 of Part 2, I think it only right to say that in so far as the author's explanations are, in my opinion, correct, they were anticipated by me in a lecture I gave at the Graduates' Society of the London Institution of Mechanical Engineers, in February, 1905. In proof of this, I enclose an extract A from "The Engineer" (where some parts of that lecture were published) of April 14, 1905.

36 I regard Mr. Taylor's explanation of the heating of the tool

as erroneous, as I have proved in an article published by me in "The Engineer" of June, 1904, that the work done against friction is only about 13 per cent of the whole, and the tool is consequently chiefly heated *by conduction* from that part of the shaving where the maximum twisting is occurring in the chip.

37 This fact leads directly to rational methods of deducing the expected durability of tools, as depending on tool angles and areas of chip.

38 I cannot conclude without saying that the results obtained by the author with regard to the most economical cutting speed, as dependent upon the proportion of time spent in cutting to time spent in redressing and regrinding, are, in my opinion, of the greatest practical value to all engineers.

I look forward to the deeper study of the author's results along this line with a profound sense of their practical importance and economic significance.

MESSRS. ADAMSON AND NICOLSON

THE AUTHOR We feel especially indebted to Messrs. Adamson and Nicolson for taking the time and trouble to write at such length in criticism of our paper "On the Art of Cutting Metals," the more so as they are both such busy men. Perhaps no two men are better qualified through their large personal experience to criticise a large part of the work of other people in this field.

2 In Par. 37 of Mr. Nicolson's criticism, he states that in the "Engineer" of June, 1904, he pointed out the fact that the heat of the chip is chiefly caused or generated by the deformation which the metal of the shaving undergoes as it is being torn, crushed, and sheared away from the body of the forging. I have no doubt that Mr. Nicolson is correct in saying that more heat is generated through this distortion of the chip than is produced by the friction of the chip against the surface of the tool. In describing the theory upon which tools work and are destroyed, this fact had entirely escaped our attention, and we are indebted to Mr. Nicolson for calling attention to it.

3 He is, however, wrong in assuming that the tool is mainly heated by *conducting* the heat from the chip to the tool. On the contrary, at all times during the operation of cutting, heat is continually being conducted from the tool to the chip, and this will be clearly evident to anyone who observes closely a modern high speed tool when cutting at its maximum speed. In this case, the nose of

the tool, for a considerable distance below the cutting edge, will be seen to have a dull red heat, while, on the other hand, the chip itself, with the exception of a few loose films of metal on the under side of the chip, is never heated to a red color. It is needless, of course, to point out that heat will always flow from the hotter to the colder body, therefore the chip is continually conducting heat away from the tool.

4 The amount of heat developed through bending and distortion in the chip, however, is, as Mr. Nicolson points out, a very important feature in the whole problem, and undoubtedly if this heat were not generated in the chip through its distortion, the chip would then be so much colder that it would carry off the heat from the nose of the tool much more rapidly, and higher cutting speeds could be attained. This heating of the chip through bending or distortion also accounts for the fact that, in order to be most effective, a stream of water should be directed right on to the chip at the point at which it is being cut away from the body of the forging. The water, which removes a certain amount of the heat generated in the chip, enables the chip to carry off more of the heat from the nose of the tool, and so permits an increase of 40 per cent in the cutting speed. The observation and statement of these facts constitutes another important contribution by Mr. Nicolson to the art of cutting metals.

5 In Par. 20 of Mr. Adamson's criticism, and in Mr. Skegg's criticism, these gentlemen take exception to our statement that the body of the tool should be twice as high as it is wide, as illustrated in Figs. 14, 15, and 16 on Folder 2, and referred to by us in Par. 415 to 421. If it frequently occurred that the feeding pressure on the nose of the tool was equal to the driving pressure on the top surface of the tool, then Mr. Adamson would be correct in stating that a square shank is the proper section for a tool. But it is of very rare occurrence, as carefully pointed out by us, that the feeding pressure is equal to the driving pressure. In deciding the feed gearing for a lathe, we have stated that the feeding pressure should be counted upon as equal to the driving pressure, because, if this only occurred once in three or four months, it would be sufficient to smash the feed gears of the machine, unless they were especially designed to meet this heavy pressure.

6 On the other hand, the normal feeding pressure, which occurs perhaps in ninety-nine out of a hundred cases, is only from 15 to 40 per cent of the downward pressure on the tool. The tool itself, then, should be designed to suit these normal conditions, while the feed gears should be designed to withstand the most severe conditions, even although they occur very seldom.

7 I am particularly pleased to note that Mr. Nicolson's observations as to the manner in which the chip is cut or torn from the forging, as described by him in Par. 36, agree so nearly with our own as described in Par. 153, etc. This fact makes both of these observations much more valuable and especially so since in conducting the experiments and in describing them, neither set of experimenters was even aware that the other was working in this field.

8 Answering Mr. Adamson's question (Par. 19) as to whether there is ground for the prejudice which exists in England in favor of using a grindstone for sharpening high speed tools, instead of an emery wheel, I think there is ample ground for this preference. Unless a very heavy stream of water is directed continuously upon the cutting edge of the tool throughout the time that it is being ground upon an emery wheel, the tool is likely to be seriously injured in the grinding. The ordinary grindstone runs so much slower that it is not so likely to overheat the tool in grinding. However if a proper stream of water is used, there is no question that the emery wheel, with grit of proper coarseness, is greatly to be preferred to the grindstone. It will grind six or eight times as fast under the most favorable conditions, and will not injure the tool in the least.

9 Again, answering Par. 24 of Mr. Adamson, the use of tool holders involves inserted tools of high speed steel which are small in their body, and for this reason they contain too small an amount of metal to properly carry away the heat generated by the friction of the chip, and they therefore necessitate much slower cutting speeds. In addition to this, the size of tools inserted in the tool holder is generally too small to permit of the proper curve for the cutting edge. It is our practice, in the shops which we standardize and systematize, to use practically no inserted tool holders. The one exception which we make to this rule is in the case of tools of the largest size, as, for instance, those used in cutting heavy armor plate or the largest size steel forgings. In this case, a very large inserted tool can be used with advantage.

10 Mr. Adamson's objection in Par. 11 and 12, to the use of a "cut gage" as illustrated by us in Folder 9, Fig. 55, can be attributed only to the fact that he has never used one. I must repeat that this is the only means which we know of by which the same depth of cut can be maintained uniformly throughout the experiment, and it is needless to call attention again to the necessity for maintaining a uniform depth. The use of the micrometer on the feed screw, as suggested by Mr. Adamson in Par. 11, does not enable the operator to obtain the depth of cut which he aims at, nor does it enable him to

maintain this depth uniform, when once obtained. In proof of this, I would call attention to the fact that, throughout the experiments published by Mr. Nicolson in the Transactions of our Society, Vol. 25, Paper No. 1035, June, 1904, in which the micrometer apparatus was used, invariably a given depth of cut was aimed at, and a different depth of cut was actually attained in the machine. It is an excellent plan, on the other hand, as suggested by Mr. Adamson, to have a revolution counter attached to the spindle of the lathe by which to check the other measurements made.

11 Answering Mr. Adamson's Par. 25, it has been our custom to set our tools with their cutting edge practically on the level with the center of the lathe.

12 Referring to Mr. Adamson's Par. 26, as to the difference between acid and basic forgings, we do not look upon the chemical analysis of a given forging as sufficient data for determining its cutting properties. The combination of tensile strength and extension, as indicated in our Table 141, Folder 23, and in the paragraphs throughout the paper referring to this, is the best guide to the quality of the metal being cut.

13 In Mr. Adamson's criticism in Par. 28, and also in Mr. Skegg's criticism, Par. 3, these gentlemen have evidently overlooked our chapter on the effect of the quality or hardness of metal upon the cutting speed, beginning with Par. 1141, and particularly to Par. 1166, in which we refer to the effect of scale on cast iron castings upon the cutting speed.

14 In reading the criticisms of both Messrs. Adamson and Nicolson, the impression is given that in writing the paper we have spoken contemptuously, or at least in a slighting way, of the work which they have done. If, in writing our paper, I have given this impression, I wish most sincerely to apologize. I have the highest respect for the work of both of these gentlemen, and am sure that with their special ability and training they would have accomplished much more in the same space of time than we have done. We have clearly stated, in writing the paper, that we worked for fourteen years with false and unscientific standards, and I have not the slightest doubt that the gentlemen in charge of the Manchester experiments, and particularly Messrs. Nicolson and Adamson, would have adopted thoroughly scientific methods in a much shorter time than this. It must be remembered that the Manchester experiments extended only over a period of less than a year, and it is not to be expected that, even with the special ability of this committee, they should have hit upon thoroughly scientific methods in so short a time. It was my sincere

endeavor in writing the paper to make my criticism of the work of other experimenters strictly impersonal. Our only object in offering criticism being that of inducing any future experimenters in this field to adopt the very best, the most modern, and the most scientific methods. A more careful reading of our paper will, I think, make it clear that our criticism throughout was aimed at unscientific methods, whether they were used by us or by other people; and in fact for every word that we have used in the criticism of the work of other experimenters, we have written ten words in severe and frank criticism of our own shortcomings. Many of our sentences bearing upon this matter must have been hastily read or else overlooked by Messrs. Adamson and Nicolson. We would, therefore, call especial attention to the following sample paragraphs as relating to this subject.

Par. 32 The writer has no doubt that many of the discoveries and conclusions which mark the progress of this work have been and are well known to other engineers, and we do not record them with any certainty that we were the first to discover or formulate them, but merely to indicate some of the landmarks in the development of our own experiments, which to us were new and of value. The following is a record of some of our more important steps.

Par. 58 This method is, of course, much quicker than the thoroughly scientific type, and it is largely for this reason, in the opinion of the writer, that almost all of the other experimenters in this field have chosen it. Several of the experiments of this type have proved most valuable and developed much useful information, and it is with hesitancy that the writer criticises the work of any of these experimenters, since he appreciates most keenly the difficulties under which they worked, and is grateful for the information contributed by them to the art. After much consideration, however, he has decided to point out what he believes to be a few errors made by these experimenters, with the same object which he has in indicating our own false steps: namely, that of warning future investigators against similar errors.

Par. 59 Almost the whole course of our experiments is marked by imperfections in our methods, which, as we have realized them, have led us to go again more carefully over the ground previously traveled. These errors may be divided into three principal classes.

Par. 60 (A) The adoption of wrong or inadequate standards for measuring the effect of each of the variables upon the cutting speed.

Par. 61 (B) Failure on our part from various causes to hold all of the variables constant except the one which was being systematically changed in order to study the effect of these changes upon the cutting speed.

Par. 68 It was only after about 14 years' work that we found that the best measure for the value of a tool lay in the exact cutting speed at which it was completely ruined at the end of 20 minutes. In the meantime, we had made one set of experiments after another as we successively found the errors due to our earlier standards, and realized and remedied the defects in our apparatus and methods; and we have now arrived at the interesting though rather humiliating conclusion that with our present knowledge of methods and apparatus, it would

be entirely practicable to obtain through four or five years of experimenting all of the information which we have spent 26 years in getting.

Par. 69 The following are some of the more important errors made by us:

Par. 70 We wasted much time by testing tools for a shorter cutting period than 20 minutes, and then having found that tools which were apparently uniform in all respects gave most erratic results (particularly in cutting steel) when run for a shorter period than 20 minutes; we erred in the other direction by running our tools for periods of 30 or 40 minutes each, and in this way used up in each single experiment so much of the forging that it was impossible to make enough experiments in cutting metal of uniform quality to get conclusive results. We finally settled on a run of 20 minutes as being the best all-round criterion, and have seen no reason for modifying this conclusion up to date.

Par. 86 Broadly speaking, it is unwise to draw conclusions and make formulae from experiments in which more than one variable is allowed to vary in the same trial. This criticism is made in no sense to belittle the value of the work done by others, but with the object to pointedly call the attention of future experimenters to such errors as have been made primarily by ourselves and also by others.

15 It is only after considerable hesitation that I have decided to answer somewhat in detail the criticism presented upon our paper by Messrs. Adamson and Nicolson, and my principal reasons for doing so will be found in the footnote to Par. 112 of "On the Art of Cutting Metals." In considering the criticism of these gentlemen, it should be understood that advance proof sheets, printed upon very poor paper, were sent to them, and that when they wrote the greater part of their criticism only about two-thirds of the reading matter of the paper was in their possession, and probably not one-third of the tables and cuts which were finally printed on the folders; and also that only a very short time was given them in which to read the paper and write their critiques. Much of what has been said by these gentlemen must, therefore, be attributed to a hasty reading of a very imperfect paper.

16 For example, both criticise the title of the paper as being entirely too broad. On the outside of the Proceedings and at the opening chapter of the paper, the title is "*On* the Art of Cutting Metals." In hastily reading this title, however, both Messrs. Nicolson and Adamson have overlooked the word "on." Certainly the assumption that this paper dealt with even any large part of the art of cutting metals would have been false. It is, however, proper, I think, to say that the paper is written "*On* the Art of Cutting Metals."

17 Again, in Par. 13 of Mr. Adamson's discussion, I quote as follows:

"There are many conclusions given in Mr. Taylor's paper as the result of his long continued experiments, but the grounds upon which they are based, or the method by which they may be applied in practice, are omitted. For example, I may refer particularly to Par. 279 to 288, etc."

18 If we had (as Mr. Adamson says) given the conclusions stated in Par. 279 to 288 without further reference to the data upon which these conclusions are based, Mr. Adamson's words of censure would have been entirely inadequate. The conclusions from Par. 279 to 288, in fact, constitute a very brief summary of almost all of our experiments, and a little more careful reading on the part of Mr. Adamson would have shown him that for each of these conclusions there is an entire chapter in the paper, giving in detail both the experiments and the reasoning upon which the conclusion is founded.

19 It is true that in the Manchester Report every important detail regarding the individual cut of each tool experimented with is recorded, and this data is both interesting and valuable. The work of the Manchester Committee, however, includes, all told, only about 220 experiments, and in describing these experiments, including the discussion, 130 pages of printed matter were issued by Messrs. Adamson and Nicolson. It will be remembered, on the other hand, that we made and recorded between thirty and fifty thousand experiments. If we, therefore, had taken proportionately the same amount of space in recording and describing and in the discussion of our experiments as was taken by Messrs. Nicolson and Adamson in describing the Manchester experiments, our work would have filled a volume of say about 24,000 pages. It is with regret that I read in Par. 29 of Mr. Adamson that he was "nauseated" by the bulk of our paper and our constant repetition of facts. He would indeed, however, have been a sick man if we had followed his advice and recorded each one of our forty thousand experiments, as was done in the work of the Manchester Committee.

20 We must also attribute to a hasty reading of our paper Mr. Adamson's remarks in his Par. 21, in which, if I read him aright, he rather insinuates that we are holding back some much needed data. In the Manchester experiments, steel forgings were classified only into three broad classes, "soft," "medium" and "hard," and he accuses us of withholding in our paper data and constants relating to all except "medium steel." Mr. Adamson has, however, failed to note on our slide rules (Folder 11, Fig. 79) that we divide the metals worked upon in a machine shop into 40 classes, instead of only three. He has overlooked our Par. 1133, etc., regarding the classification of metals and also our large table (Folder 23, Table 141), in which we record the chemical and physical properties of 40 different forgings, with their appropriate cutting speeds and a formula which expresses fairly well the relation existing between cutting speed and tensile strength, and percentage of elongation in steel forgings.

21 Answering Mr. Adamson's criticism in Par. 21, that our formulae are too elaborate: Our formulae are all intended for use in making slide rules. These slide rules must be made by something of a mathematician, though there is but little difficulty in constructing them, once the necessary formulae are given. In our judgment, no shop foreman should be bothered to use a formula, however simple. The slide rules can be used by any mechanic, and require no mathematical knowledge whatever for their use.

22 In the reference, in our paper "On the Art of Cutting Metals," to the Manchester experiments conducted by Messrs. Adamson and Nicolson, *et al.*, our principal criticism was that these experiments while they gave exceedingly interesting and valuable data—the most complete heretofore published—yet they were not conducted upon truly scientific principles, mainly for the reason that the joint effect of four or five variables was experimented upon at the same time. Our main contention throughout our paper is for the necessity of determining the effect of each one of the twelve variables independently. A considerable portion of both Mr. Nicolson's and Mr. Adamson's criticism consists in defending the method used in the Manchester experiments of determining the joint effect of several variables as being correct. With this part of their criticism I must take issue, directly and emphatically. It is by no means correct for Mr. Nicolson to state, as he does in Par. 13 to 23, and particularly in Par. 15, that his formula, which omits eight of the variables in the problem, is to be depended upon. These eight variables, which Mr. Nicolson implies do not exist, and which his formula in Par. 13 entirely ignores, are facts, and facts which have taken us years of patient and costly work to investigate. It would be useless for us to again point out the existence and the effect of each of these eight variables upon the problem. As a single sample, however, of the eight, I would refer to the thickness of the shaving which we, in our paper, treat as one of the most important of the variables calling for investigation. Mr. Nicolson, in Par. 10 to 13, etc., attempts to prove that the thickness of the shaving is not an independent variable. His claim is, in effect, that doubling the thickness of the shaving would have the same effect on the cutting speed as doubling the depth of the cut, for example; or, in other words, that the real variable is the sectional area of the shaving, namely, the thickness of the shaving multiplied by the depth of the cut. He has evidently completely overlooked or misunderstood the experiments described in Par. 292 to 298, and in Par. 299 to 306, in which it is most conclusively proved that a given variation in the thickness of the chip produces three times as much effect upon the

cutting speed as a corresponding variation in the depth of the cut produces.

23 Mr. Nicolson has also evidently overlooked all that we have written in the paper as to the effect which the curve of the cutting edge of the tool has, first, upon the thickness of the shaving, and indirectly on this account upon the cutting speed of the tool. Mr. Nicolson in his criticism implies, if he does not directly claim, that the curve of the cutting edge of the tool has practically no effect upon the cutting speed, as this is one of the eight variables of which his formula takes no account, and which he claims need not be considered. And yet it is a fact, as stated by us in conclusion, Par. 282, and in greater detail in the chapter on "The Line or Curve of the Cutting Edge," beginning with Par. 1169, that a tool having a broad cutting edge (the effect of which is to diminish the thickness of the shaving to such an extent that it becomes exceedingly thin), can be run at six times as high cutting speed as, for instance, a thread tool can be run, or an old-fashioned diamond point tool. Surely a formula such as Mr. Nicolson's should not be used which neglects a variable so important as this. We have gone to great length in the paper to make it clear that it is the thickness of the chip which is the main factor, in allowing high cutting speeds for tools with broad cutting edges. And yet Mr. Nicolson claims that neither the thickness of the chip nor the shape of the cutting edge of the tool need be practically considered in the problem.

24 It is entirely true that a tool could be made, having such a curve for its cutting edge that, for example, a cut with a depth of $\frac{1}{8}$ of an inch and a feed of $\frac{1}{8}$ inch would have almost the same cutting speed as would accompany a cut of $\frac{1}{2}$ inch depth and $\frac{1}{32}$ inch feed. But this result would be brought about because the curve of the cutting edge had been carefully so shaped that the thickness of these two shavings would be practically the same. It is likely that this possibility has been overlooked by Messrs. Nicolson and Adamson. I would, therefore, refer them to diagrams on Folder 16, Fig. 111 and Fig. 112, and to diagrams on Folder 17, Figs. 116 and 120, with the reading matter in the body of the text which accompanies these diagrams. Comparatively little study of the principles there discussed will enable anyone to make a tool having a cutting edge in which the thickness of the shaving will be practically the same for these two cuts, which differ so greatly in their depth and in the coarseness of their feed, and it is even possible that, having accidentally used a tool approximating to this shape in their experiments, may have misled Messrs. Nicolson and Adamson into the false belief that the thickness of the shaving need not be considered as an independent variable.

25 In walking through a machine shop, it is the larger and heavier cuts which attract most attention, and are of the greatest interest. And we are prone to forget that machinists, who are using the smaller and less spectacular lathes and machine tools, are paid *about* the same wages as those who are running the larger tools, and that, therefore, it is just as important that proper combinations of cutting speed and feed should be used on the small machines as on the large.

26 It is not unnatural therefore that Mr. Nicolson should fall into the error, as he does in Par. 16 and following, of implying that in experimenting upon the laws of cutting metals, feeds finer than $\frac{1}{16}$ of an inch are of comparatively little consequence. (In the Manchester experiments no feeds finer than $\frac{1}{16}$ inch were used.) It is a fact, however, that in the average machine shop throughout this country, more cuts are taken by tools with a feed as fine as $\frac{1}{32}$ inch than are taken with coarser feeds than this. Therefore, it becomes of the greatest importance to investigate the laws affecting feeds as fine as and finer than $\frac{1}{32}$ inch, and we have devoted a very considerable portion of our paper to describing experiments of this nature. Mr. Nicolson, in inferring, as he does in his Par. 16, that we mean in our statement in Par. 252 that "experiments made on cuts with a feed as light as $\frac{1}{32}$ of an inch are worthless for determining the laws of cutting speeds," has failed to understand the meaning which we intended to convey in this paragraph, namely, that if one intended to investigate such elements as the following for example: the quality of a given tool, or the effect of a definite type of treatment for a tool, or the effect of a stream of water in cooling a tool, it was inadvisable to use a feed smaller than $\frac{1}{16}$ inch or a depth of cut less than $\frac{3}{16}$ inch. In experiments made for such purposes this is true, because of the increased difficulty of maintaining uniform conditions when feeds finer than $\frac{1}{16}$ inch or a depth of cut more shallow than $\frac{3}{16}$ inch are used.

27 It is, however, equally true that any series of experiments for determining the laws of cutting metals or any general formulae for practical use are exceedingly incomplete which fail to deal with feeds finer than $\frac{1}{16}$ of an inch.

REPLY TO MESSRS. LE CHATELIER AND CARPENTER

28 Mr. Le Chatelier, through his invention of the electro-thermal pyrometer, and through his many investigations made possible through this invention, as to the chemical changes which take place in steel as evidenced by the "points of recalescence," or "critical points" in the heating and cooling of steels, together with their cor-

responding microscopic structures, has properly earned the title of the father of this branch of metallurgical science; and Mr. Carpenter, through his recent improvements and thorough and careful work, has added greatly to our knowledge, especially as to the facts and theories connected with modern high speed tools. We therefore feel especially complimented that these gentlemen should have taken the trouble to criticise our paper, and I wish to assure them that their kindness is most highly appreciated.

29 I am also prepared to accept Mr. Carpenter's larger experience in stating, in Par. 3-b, that hardening carbon changes to softening carbon at between 700 to 720 degrees C.

30 That element of Mr. Carpenter's criticism, however, which has the greatest interest for the writer, is his endeavor to coördinate "hardness" and "red hardness," which he does in Par. 5 to 11. Mr. Carpenter's reasoning on this subject is briefly answered by Mr. Le Chatelier, in Par. 14 of his discussion.

31 It seems desirable, however, for me to supplement Mr. Le Chatelier's remarks (made without any knowledge of Mr. Carpenter's criticism) by the following: My understanding of Mr. Carpenter's theory is that it is his opinion that the highest degree of red hardness is attained at the temperature at which the austinitic structure is changed to the martensitic, in the case of high speed steels. Now, if the martensitic structure represents steel of this type in its hardest condition—and I understand this to be the case—then I can state from extended observation that the highest degree of red hardness is not necessarily accompanied by the martensitic structure; because Mr. White and the writer examined quite a number of tools of approximately the same composition, namely, Tool No. 27, Folder 20, and all of which showed the highest degree of red hardness which had been obtained by us at that time; and these several tools, in spite of having the same degree of red hardness, each showed a different microscopic structure; and, what seems of equal importance, they showed a very great variation in their hardness as tested with the file; some of them being exceedingly soft, while others were very hard. As stated before in our paper, we have obtained the highest degree of red hardness by burying tools in lime immediately after heating, say, to 1200 degrees C.; and also in a tool of similar composition by quenching in cold water after heating to 1200 degrees C. In the case of the lime-cooled tool, as you may imagine, it was very soft when tested with the file, while the water-cooled tool was very hard, and yet the same degree of red hardness was found in the two tools—*i. e.*, they both had the same "standard speed." We have never, however, made a series of experi-

ments of this kind with tools of the composition of No. 1 on Folder 20, and it may be that the highest degree of red hardness could only be attained in the case of steel of No. 1 composition when it has the martensitic structure. All of our experience, however, would indicate the probability that with steel of this composition the highest degree of red hardness could be attained with several different microscopic structures; and if this proved to be true, as we found it true in the original high speed steels with which we experimented, then I feel that we would be justified in repeating our assertion that there is no traceable relation between hardness and red hardness.

32 It would be exceedingly interesting to make experiments of this kind with steel of No. 1 composition, Folder 20. No doubt, a lime-cooled tool would exhibit a totally different microscopic structure from a water-cooled tool, and I believe that in cutting medium or soft metals the lime-cooled tool would show practically the same red hardness that would be shown by the water-cooled tool. I think that the description given by Mr. Carpenter in his discussion (Par. 7 to 10) of the relation of microscopic structures to the elements of tungsten chromium on the one hand and to red hardness on the other hand, is the simplest and clearest piece of writing on this subject that has come to my attention. I am very much afraid, however, that it does not represent the facts with regard to red hardness, which, after all, is the useful property of high speed steels.

33 I hope that Messrs. Le Chatelier and Carpenter will continue their most interesting investigations, and it will give me great pleasure to coöperate with them at any time.

34 It is needless to repeat, however, that a thorough test for red hardness in tools, according to the method of "heating and running," is both expensive and takes a great deal of time and calls for elaborate apparatus, and that nothing short of a very careful and thorough test of this nature should be undertaken.

REPLY TO MESSRS. J. E. STEAD AND JOHN KEY

35 Messrs. J. E. Stead and John Key, in Par. 2, speak of the trouble which comes from wear of the lathe center in turning with high speed tools. This can be obviated by providing the lathe with centers made of a high speed steel, properly treated. The quality of red hardness in these centers is just as valuable for resisting wear at high rotative speed of the work in a lathe as the same quality is in high speed tools for cutting the metal.

REPLY TO MR. BLAUVELT

36 I have not yet had the opportunity to read the patent referred to by Mr. Blauvelt. Mr. Blauvelt justly says, however, that it is not a matter of surprise that similar investigations should be carried on by two different sets of people entirely without knowledge on the part of either. This is a matter of very frequent occurrence.

REPLY TO MR. W. S. HUSON

37 I have never found a single instance in which it was impossible to do accurate roughing work with high speed tools, and I feel sure that if Mr. Huson had himself experimented on a series of printing press beds, such as he refers to, that he would have succeeded in getting as true work with high speed tools as he did formerly with the old low speed. There was something wrong, either with the shape or treatment of his tools, or with his method of setting the work on the planer. We find it, however, almost uniformly the case that a machinist who has worked for perhaps years on a particular class of work at a given speed, with the old grade of tools, will maintain that this particular kind of work cannot be machined with the high speed tools, and someone must come in from the outside and prove that the work can be just as accurately done with the high speed tools as with the old style.

REPLY TO MR. FRED. M. OSBORN

38 I must take exception to Mr. Osborn's statement that the original Mushet tools can properly be called high speed tools. The analyses of the Mushet tools, one made in 1898 and the other in 1894, will be found in Nos. 65 and 71 of our Folder 22, Table 140. It will be seen that one of these tools contained 0.398 of chromium, while the other contained 0.490 of chromium, and that both of these tools contained more than 2 per cent of manganese. It is our observation that no tool can be called in any sense a high speed tool which does not contain more than 0.50 per cent of chromium. During the many years in which Mushet tools were used in this country, I met many times the salesmen who were introducing Mushet self-hardening steel, and I also had the pleasure of meeting Mr. Jones, who is referred to by Mr. Osborn, and not one of these men ever suggested that better results could be obtained with Mushet tools by heating them to a high heat and then blowing them in a blast of air. On the contrary, their directions were most positive not to heat the Mushet steel beyond a cherry red for obtaining the best results, and as an

indication of the proper heat a red colored label was pasted on to much, if not all, of the Mushet steel.

39 It was the substitution of chromium for manganese in self-hardening steel which paved the way for the modern high speed steels, and this substitution was not made in the Mushet steel by Messrs. Osborn & Company. It was made, however, by a number of makers of self-hardening steel who were competing with the Mushet steel.

REPLY TO MESSRS. RICE, BANCROFT, HATHAWAY AND LEWIS

40 The criticisms of Messrs. Rice, Bancroft, Hathaway and Lewis are of the greatest interest both to me and my associates, as dealing with the broader practical application of the facts recorded in the paper. Our interest in the scientific, or what one might call the intellectual element of the art of cutting metals, has been of course very great; but after all the true measure of the value of this work should be the actual every-day help which will be given by these laws to the superintendents, foremen, and mechanics in our machine shops. And the large practical results to be realized from this work are, in my opinion, to such an extent bound up with the general principals of our whole system of management, that it is the relation of the laws which we have determined to the mechanism which we have developed for their application to this system of management, which holds for us the greatest interest.

41 I must again repeat that I feel quite sure that the real benefit will be realized from these laws only when they are used for the purpose for which the investigation was originally started, and for which it was carried out through so many years, namely, that of enabling the management of a shop to assign a daily task in advance to each machinist, giving him written instructions as to the shape of tool, the depth of cut, the feed, the speed which he must use, and the total time which he is to take in doing each job, and then paying him a large bonus for carrying out his orders. When the human and other mechanism is once established in a shop for accomplishing this end, results which are truly astounding are sure to follow, and we feel especially indebted to Messrs. Bancroft, Hathaway and Lewis for indicating this fact. And I wish again to emphasize what I have before said, that anxious as we are to have these laws of cutting metals and our slide rules properly used, and more particularly to have the general principals of our system of management adopted, we hesitate greatly in advising any one to attempt a change from the old methods to task management, without the regular assistance of men

who have been especially trained in doing this work; and Mr. Lewis has rendered a service to those intending to adopt these principles by so clearly calling attention to this fact.

FINAL CLOSING REMARKS

42 I wish to say for myself, as well as on behalf of Messrs. White, Barth and Gantt, that we have been fairly overwhelmed with the commendation which our paper has received from so many men, and also from the technical journals, both in this country and in Europe. We are especially pleased and grateful that men of such eminence and of such widely divergent interests as Messrs. Henry R. Towne, James M. Dodge, Calvin W. Rice, J. S. Bancroft, H. K. Hathaway, Wilfred Lewis, J. T. Hawkins, L. P. Breckinridge, Oberlin Smith, W. S. Huson, and W. H. Blauvelt, in this country, should have taken both the time and trouble to read and to criticise our work from their various viewpoints. And it is in some respects even more gratifying that we should have had the added help and criticism of such noted foreigners as Monsieur H. Le Chatelier, the most eminent French metallurgist, and Monsieur C. Codron, the able experimenter and analyst, who has written upon many of the elements of the art of cutting metals, as well as that of the several English authorities who are perhaps best qualified to criticise this work, namely, Mr. H. C. H. Carpenter, Dr. J. T. Nicolson, Mr. Daniel Adamson, Mr. S. Skeggs, Mr. J. E. Stead, Mr. John Key and Mr. F. M. Osborn.

43 It is our hope that our paper may excite a sufficiently lasting interest in the subject to induce others to continue the much needed experiments in this field, and it is needless to add that we shall be at all times not only ready but most pleased to coöperate with any other experimenters.

44 In conclusion, I can but express a certain surprise and regret that our paper "On the Art of Cutting Metals" has attracted so much more attention than has been given to our various papers on shop management, which, after all, is the real vital subject in which we are most interested, and of which the art of cutting metals constitutes, on the whole, merely one of the important elements.

No. 1120

SAW TOOTH SKYLIGHT IN FACTORY ROOF CONSTRUCTION

By FRED S. HINDS, BOSTON, MASS.
Member of the Society

1 Before Dr. Cartwright invented the power loom in 1785, the cotton spinning factories had attained quite a considerable growth in the Lancashire District of England.

2 When the cotton loom came into practical use, weaving was carried on in the homes of operatives, up to the time when, with the increase in cotton weaving and the advent of the power loom, it devolved upon the progressive operator to branch out into a new plant and set up a few power looms, as a weaving establishment. This naturally was a one-story building and in time was designated as a "weave shed." Thus was commenced a system in textile manufacture which became popular, and is today, in England and on the Continent. The spinning factory produces the yarn and the weave shed the cloth.

3 As these weaving companies changed from plain to fancy and colored weaving, and increased the width of the weave sheds to gain greater area, some method of roof lighting became necessary. Thus necessity, the mother of invention, produced the saw-tooth form of roof skylights for lighting the center of the wide one-story buildings.

4 The English and Continental manufacturers were not long in appreciating the value of this method of lighting. Today they are found on all kinds of manufacturing plants.

5 The principle in this so-called "saw-tooth" form of skylight is the diffusion of a strong north light upon the work in process. This is secured by the green-house type of sash, applied to one side of the saw-tooth and exposed to the north light, the glass being set at such an angle as not to admit the direct rays of the sun. This type of sash reduces to a minimum the wood work, and thus minimizes the obstruction of light and the casting of shadows.

Presented at the New York meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

6 The result is a practically continuous window of glass, which gives a far greater lighting area than wall and windows, or than skylights placed in the usual manner at intervals.

The skylights may run across the building, or lengthwise of the building, so that the glass may face to the north. Placed across the building, they are somewhat simpler in construction and thus less expensive.

METHOD OF CONSTRUCTION

Today there are two constructive designs in applying these skylights; one English and the other American.

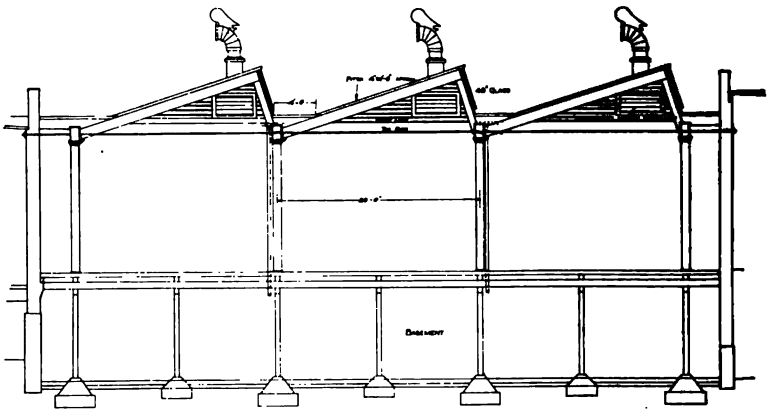


FIG. 1 STANDARD SAW-TOOTH SKYLIGHT IN MILL CONSTRUCTION OVER A DEPARTMENT OF THE FIBERLOID COMPANY'S PLANT, INDIAN ORCHARD, MASS. NOTE THE FLAT ROOF BETWEEN SKYLIGHT AND THE VENTILATORS

7 The English design is in the true form of saw-tooth; the American, in the modified form, or semi-saw-tooth flat roof design.

8 The English design was Americanized by the writer, as shown by the accompanying illustrations and some of the photographs, to meet the conditions of our rigorous and changing climate.

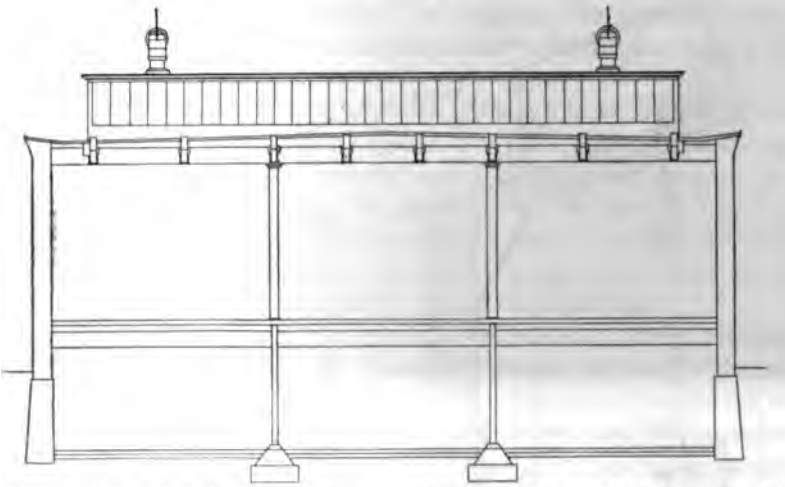
9 In 1885, when associated with a mill architect and engineer, the writer was called upon to design some method of roof lighting on a one-story addition to be built in a mill yard area, formed by three buildings in the shape of the letter "U." The problem was to light this area and project light into the first story of the then existing buildings so as to make up for the loss of light due to roofing over the yard area.

10 This same year the writer happened upon an English type of

aw-tooth lighted weave shed in connection with a mill plant in the ame neighborhood.

11 Upon examination it was found to be giving trouble from leaks. n this type of roof the acute angle formed by the two sides of the kylight was finished in the form of a gutter, made up of sheet metal. These gutters fill up with snow and water which, melting and freezing, ause excessive expansion and contraction, and the result is cracks nd broken joints.

12 The writer, profiting from this experience, designed a semi-aw-tooth flat roof. In this type the space between the skylight was



IG 2 FRONT VIEW OF SAW-TOOTH SKYLIGHT, FIBERLOID COMPANY'S PLANT

inished in the usual gravel roofing, the slant of the roof conveying he roof-water to the edge or center of the roof, as the case may be, arrying off the water either by gutters on the outside or by conductors down through the building.

13 The angle of the glass is designed by some at 60°, but when he sun is in the zenith it will shine through these skylights. This natter has been lost sight of, as one of the leading features in the rinciple of saw-tooth skylights is the elimination of the direct rays. 'or the South the writer has used 77° and for the North, 71°.

14 In my later designs I have reduced the wide flat roof space etween the skylights, and somewhat reversed the modification, eturning more closely to the English system, but at the same time etaining a narrow flat roof between each skylight, varying in width rom 24″ to 48″, according to circumstances. (See Fig. 1, 2 and 3.)

15 The flat gravel roof was then reduced from ½″ to ¼″ pitch to the foot, to avoid the building up of such high forms as would be necessary with ½″ pitch.

16 The height of the glass is based entirely on the class of manufacture and amount of light required. Four, five and six feet have been my usual basis to work from in determining the size to use. Four feet high, with skylights 20′ apart, is good for general use. Five feet is used for special cases, such as high erecting shops, and six feet for cases where extra strong light is required.

17 In the year 1900 the writer was called upon to design, in connection with the planning of a southern cotton factory, a weave shed for weaving pattern fabrics. In adopting the saw-tooth skylight, all cross timbers had to be eliminated to avoid the casting of shadows.

18 Appreciating the value of north light and to avoid any direct sun rays, the sash was set at an angle of 77°. This angle, which brings the sash only 13° from the vertical, and therefore not at a great inclination, led to the belief that the elaborate trussed form in framing these skylights was entirely unnecessary to resist this small amount of thrust. I therefore, adopted the tie-rod as the lower chord spanning from column to column, anchoring at each end wall.

19 Fig. 3 illustrates the various details of my latest skylight design and it will be noted that both the double glazing and single glazing are represented. I would draw particular attention to the details of the metal bars. The bars and the bottom of the glass are provided with small gutters for collecting any condensation, and openings are provided in the horizontal metal work for letting out the water as it collects.

20 The double glazing is necessary for some manufacturing plants in the North, but only single glazing is used in the South.

21 The flat gravel space between each skylight and the method of flashing are also detailed.

22 One element of weakness in the construction of some roofs of this type is that the galvanized iron is continued down onto the roof and becomes a part of the flashing. True flashing, and the best, should be in about 10 oz. zinc, running up behind the counter-flashing, or outer flashing, of the skylight.

23 Fig. 3 also shows the slat walk which it is wise to provide in northern skylights, intended not only to walk upon but to facilitate the shoveling off of snow without destroying the gravel roofing.

24 This leads to the subject of snow and whether it is detrimental to the use of skylights.

25 As the prevailing winds in snow-storms are either from the north-east or north-west, it is found to be true (according to observations in a locality in Massachusetts where this style of skylight is very popular) that the wind in a high storm will blow the snow out, because of the somewhat funnel or grooved shape of the skylights. However, suppose the space between the skylights does fill up somewhat with snow, it is not a great expense to hire cheap labor to shovel out this snow, or better, install what is quite common at the roof gutter of some office buildings, a very small exhaust pipe down through the area between the skylights which can be supplied with exhaust steam, at any time, to melt the snow.

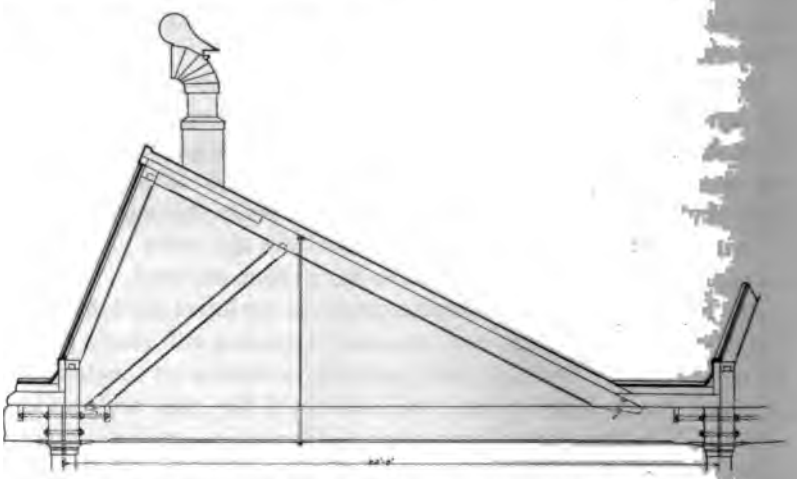


FIG. 4 ELABORATE TRUSSED FORM OF SAW-TOOTH SKYLIGHT

26 It must be conceded that, with a monitor skylight, in a drifting storm, the vertical side would resist the snow and pile it up, and naturally get the same trouble as with the saw-tooth. Right here the English system would show its serious defect. The advantage of the flat roof is that it spreads out the saw-tooth into a wider area and the snow cannot pile so deep as in the "V" form.

27 Fig. 4 illustrates the elaborate trussed form of framing. Fig. 5 a similar form in reinforced concrete. I believe it is entirely unwarranted as it increases expense in construction and becomes an obstruction to its own light.

28 Fig. 5 shows two very weak points.

29 First, you will note at "A" that the tin roofing forming the gutter, or flat valley, runs up under the slag or gravel roofing, as you

would flash under a slate roof. This is at a vertical wall. The same criticism applies at the gutter formed by the skylight itself, or at "B."

30 It is well known in building construction that the worst form of gutter is to have the slant of a roof strike up against a vertical wall where a gutter, or flat valley, must be constructed to carry away the roof water. It makes a very acute angle in which snow and water can collect. The water is taken up by capillary attraction and percolates through some crack in the roofing higher up than the highest point of the tin-work which runs up under the gravel roofing.

31 Some designs have the sash set vertically. This is uncalled-for as, with the same height of glass, if sash is set at an angle, the

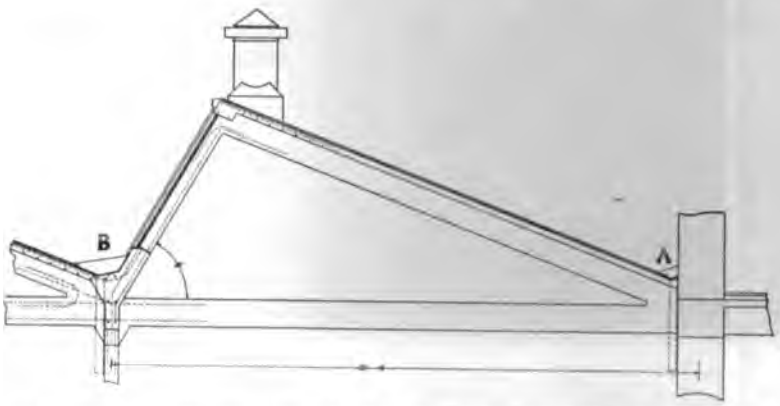


FIG. 5 SAW-TOOTH SKYLIGHT IN REINFORCED CONCRETE, WITH HEAVY CONCRETE BEAM AS BOTTOM CHORD OF TRUSS

area of direct rays of light is increased. There is also less length of slant for the back of the skylight and thus less roof area to cover.

32 This vertical design was used for the purpose of hanging the sash with weights or on a pivot. The slant from the vertical is so small there is no trouble from the weather beating in.

SASH CONSTRUCTION

33 The sashes are constructed either of wood or sheet metal. If of wood, the glazing is with putty; if of metal, the glazing is done without putty and bars are formed to take care of condensation.

34 With reference to "wood versus metal skylights," and what metal workers are doing under contract at the present time, the

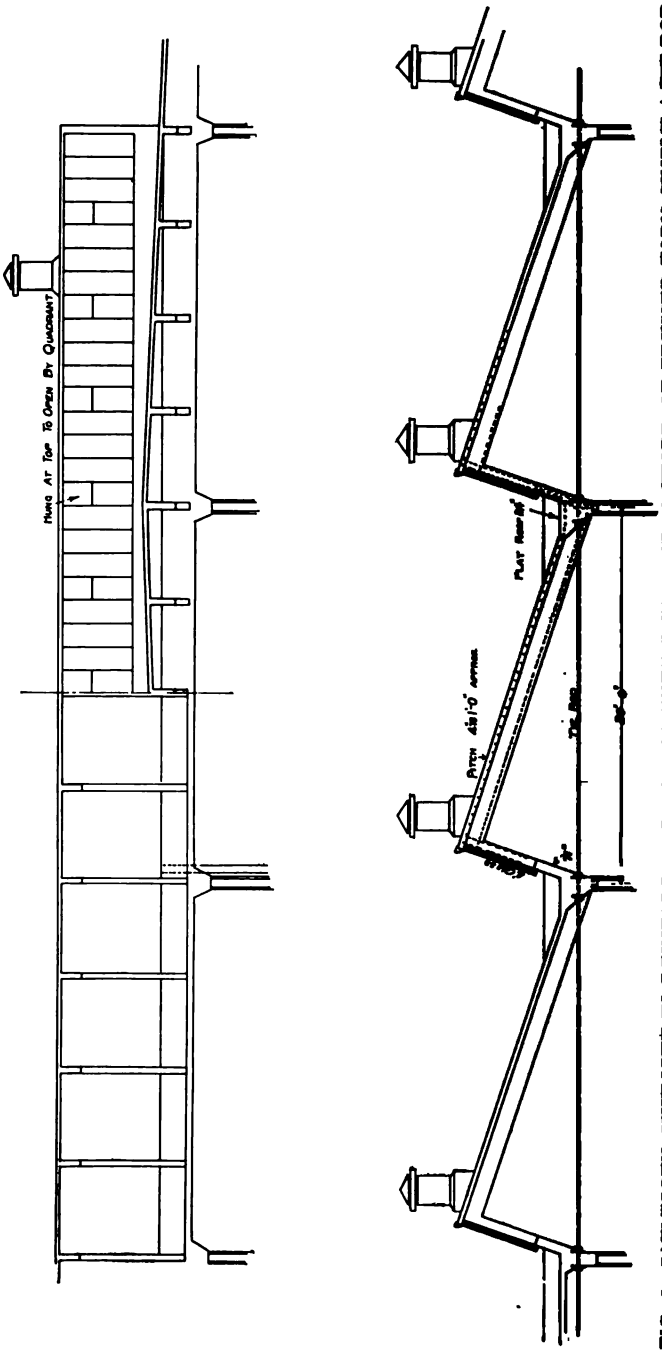


FIG. 6 SAW-TOOTH SKYLIGHT IN REINFORCED CONCRETE WITH THE BOTTOM CHORD OF TRUSSED FORM SIMPLY A TIE ROD AT THE COLUMN LINE

FIG. 6a WIDE TWO-STORY SHOP JOHN THOMPSON PRESS COMPANY'S PLANT

FIG. 7 SAW-TOOTH SKYLIGHT OVER ERECTING SHOPS OF B. F. STURTEVANT COMPANY'S PLANT
THEY HAVE THE NARROW FLAT ROOF BETWEEN BUT DO NOT SHOW ANY INDICATION OF VENTILATION

following is a quotation from a letter on the subject. "We have a contract at present for changing over four saw-tooth skylights about 200′ long x 15′ glass opening, from wood construction to metal construction. Also two saw-tooth skylights that we are erecting in metal. These are about 90′ long x 10′ 6″ glass measure. Heretofore the saw-tooth skylights for this company have been built in wood and a departure was made in favor of metal."

35 The one which is referred to as 10′ 6″ glass measure and 90′ long is illustrated by Fig. 11, which you will note is not a continuous skylight but a number of skylights with spaces between.

36 These were designed, no doubt, in this way on account of the saw-teeth running lengthwise of the building. This excessive height could have been overcome by forming a continuous skylight, utilizing the spaces between, thus reducing the height of the glass and making up for it by this increase in length.

VENTILATION

37 The subject of ventilation, in connection with this particular class of skylight, has gone through changes along with the vicissitudes of the skylight itself. When these skylights were first introduced on weave sheds of cotton factories, no ventilation was provided.

38 Later, as the skylight manufacturers developed new inventions, the Louvre ventilator was adopted and used in the end of the saw-teeth, as a substitute for round windows, which may have been hung on swivels. Next followed the usual style of galvanized iron ventilator, common in metal skylights used on other classes of buildings. The latest method is to hang one-half the length of the glass at the top and control by the usual quadrant for opening at any angle. These are good in periods of clear weather and, in connection with the roof ventilators, give a very good current of air. In stormy weather these side lights must be closed, and the ventilation is taken care of by the Louvre and the roof ventilators.

ROOFING

39 The most approved practice for covering the back of these skylights is some form of asphalt roofing, the method of applying depending upon the angle, or slant, of the roof. Those which have a slant of 4″ to one foot can be covered with the usual asphalt felt roofing and covered with gravel, the same as a flat roof. If the slant is greater, then the two upper layers of felt should be applied in what is called

FIG. 8. INTERIOR VIEW—H. J. HEINZ COMPANY'S PRINTING SHOP, ILLUSTRATING TRANSMISSION OF CONSTRUCTION

FIG. 9 ERECTING ROOM OF B. F. STURTEVANT COMPANY'S SHOP, ILLUSTRATING THE FINE LIGHTING OF CENTRAL DIVISION

FIG. 10 ROSEMARY MANUFACTURING COMPANY'S COTTON FACTORY, ROANOKE RAPIDS, NORTH CAROLINA

FIG. 11 ROOF OF GENERAL ELECTRIC COMPANY'S SHOP AT LYNN, MASS.
NOTE THESE ARE NOT CONTINUOUS SKYLIGHTS AND IN WOOD CONSTRUCTION WITH SLATE OR LONG SLANT

"prepared gravel asphalt roofing," or where slag can be procured and applied in place of gravel then the slant can be increased to 7" to one foot. The flat spaces between the skylights can be of the usual coal tar, felt roofing, and gravel, unless one prefers to have it all asphalt at a slightly increased cost.

40 Saw-tooth skylights do not add to the architectural beauty of a factory building and, therefore, I have studied to keep them down to a reasonable height, and at the same time make them high enough to give the amount of light required.

REINFORCED CONCRETE

41 The use of reinforced concrete in factory buildings suggests its adaptability to saw-tooth skylight construction. Fig. 6 illustrates how this "Americanized" saw-tooth form can be very simply constructed in reinforced concrete and embody in it all the features necessary.

APPLICATION AND SHOP ECONOMICS

42 Saw-tooth skylight construction is not only adapted to cotton factories but to factory buildings, machine shops and for all kinds of manufacturing plants, where better lighting is required than can be obtained from side windows. It is superseding the common monitor roof and is especially adapted for use over erecting rooms and crane ways. It solves the problem of the one-story flat roof machine shop and factories, where this style of construction is desirable and wide buildings are required. In shop economics, and with the extensive area of modern plants, the monitor skylight compels an excessive length in buildings, while the saw-tooth skylight admits of a proportionally greater width and less length, hence giving a more compact arrangement of the shop departments and a thus greater available area of floor space.

43 Where land is valuable, it is applicable to the two-story shop or factory, if special provision is made for lighting the first story. My latest application to a machine shop was a design for the John Thomson Press Company, see Fig. 6a, of an 80′ shop erected at Long Island City in 1905, while acting as consulting architect. This width of 80′ had two rows of columns, thus practically three 25′ divisions.

44 The manufacturer's general plan was to use the two outer divisions of first story for heavy tools and the center division for tool

room, storage, etc., and the second story for light machine tools. Over this second story, the introduction of the saw-tooth skylight was applicable and very practical. Its practical value is in the improved arrangement of tools and benches. Instead of running the benches around the room against the walls, they can be run across the room; first benches, then tools alternating down the length of the shop, depending on the nature of the product. With this system a greater production is sure to follow and with the strong roof light, a higher degree of workmanship.

45 Figs. 7, 8, 9, 10 and 11 still further illustrate the various applications of this form of skylight.

46 The three photos of the B. F. Sturtevant Co. plant were furnished through the courtesy of their engineering department and and that of the General Electric Company, through the courtesy of Mr. G. F. Baker, superintendent.

47 These two plants, so well known, were not designed by the writer, but selected to illustrate more completely the points I desire to make in the progress and modifications that these skylights have undergone to reach the present simple form of construction.

DISCUSSION

PROF. JOHN E. SWEET I am led to comment on Mr. Hinds' paper more to correct some mistakes than with an idea of adding much to its value.

2 In 1889 the weaving shed roof of the Straight Line Engine Company's Works in Syracuse was built, and I supposed at the time and until the appearance of Mr. Hinds' paper that it was the first application in this country of this form of roof to machine shop use.

3 As a full account of this roof was given on pp. 527 to 535 of the Transactions for 1893, I have only to add that it is on the English plan and without the troubles Mr. Hinds mentions, and this was obviated by making the gutters of cast iron, short enough to go between the trusses, which are only 8 feet centers, and draining each trough by a separate spout into a continuous conductor running from end to end of the building. As the troughs and conductor are inside the building and are of iron instead of wood they melt out the snow and ice before it melts on the roof and hence there is no trouble from freezing ice and snow. The troughs being in sections with a proper joint cover, expansion and contraction have no detrimental effect. So satisfactory

have been our 17 years of experience, that the same system has been adopted for the Artisan School.

4 The spans are 32 ft., trusses 8 ft. apart and the glass 6 ft. high. During the 17 winters, snow has never had to be shoveled off but once and then only because it piled up on the glass and shut out the light. In the ordinary machine shop the lower chord of the truss has, in addition to acting as a chord, another function to perform, that of carrying the line shaft and counters and two angles spaced $\frac{5}{8}$" or $\frac{7}{8}$" apart between which supporting bolts will pass, making a far more convenient arrangement than to screw coach screws into the wood girders. Concrete for this service would appear to be especially bad where shafting has to be supported. With our experience I would be as reluctant to adopt the other form as Mr. Hinds would be to adopt ours. Any kind of metal gutters if properly made will work all right if inside the building.

5 It is common practice to put trusses 16 to 20, or more, feet apart with purlines from truss to truss, then rafters and planking. Light trusses, eight or, at most, ten feet apart are better for several reasons. The purlines and rafters are dispensed with, two light trusses have less to carry than the one heavy one, they are more easily constructed and erected, and with the close spacing they are right for line shaft hangers without stringers.

6 It is claimed by the constructors of structural steel building that the large trusses and wider spacings are cheaper and the better method, but they can be just as easily mistaken as anyone else, or at least for spans of 30 or 40 feet. I am satisfied that, when considering the advantages pointed out above, they are dead wrong.

MR. G. R. HENDERSON The author of this paper refers to the proper angle for placing the skylights in the saw-tooth, and while, no doubt, this angle is correct from a theoretical point of view, as far as proper diffusion of the light is concerned, yet from practical considerations, in connection with the structure of a building, it is sometimes desirable to place these windows vertically. This will be illustrated by the accompanying cuts, which represent a locomotive erecting and machine shop now being constructed by the Missouri, Kansas, and Texas Railway from plans prepared by the writer. Fig. 1 shows the west elevation and Fig. 2 the east elevation. The saw-tooth construction will be noticed on each side of the central or higher section, and it will be seen that the windows in this saw-tooth are placed in a vertical plane. Fig. 3 makes the arrangement somewhat clearer, and while the saw-tooth windows are not actually shown,

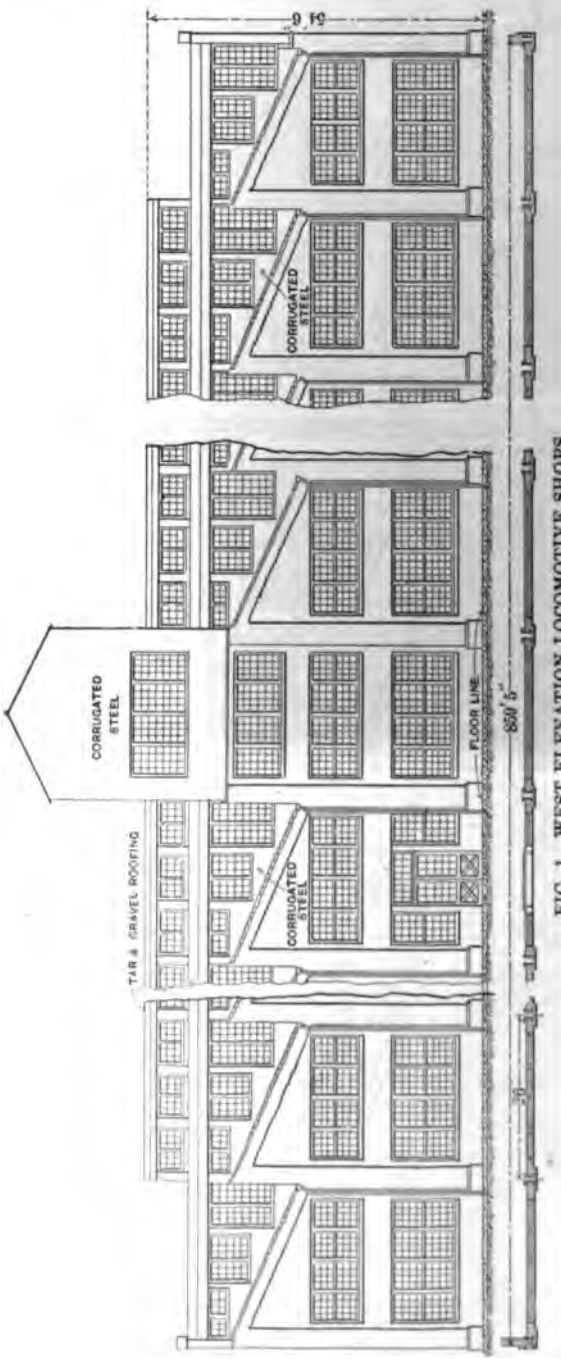


FIG. 1 WEST ELEVATION LOCOMOTIVE SHOPS

FIG. 2 EAST ELEVATION LOCOMOTIVE SHOPS

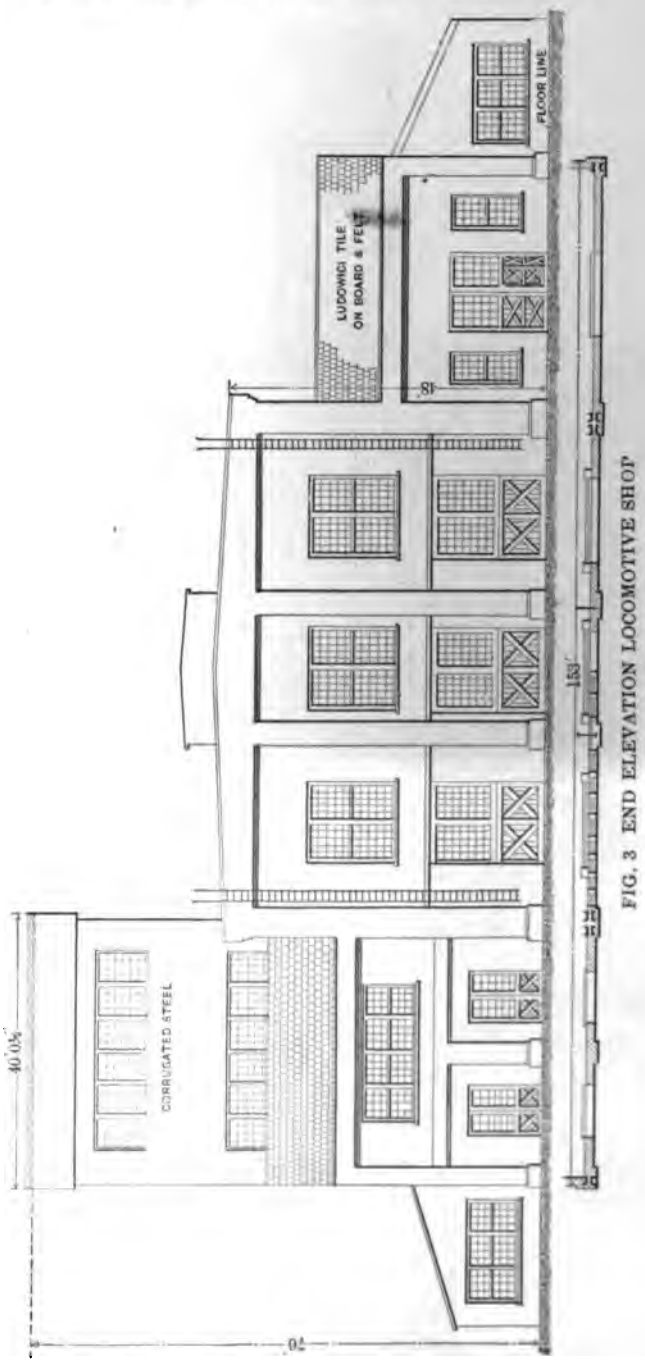


FIG. 3 END ELEVATION LOCOMOTIVE SHOP

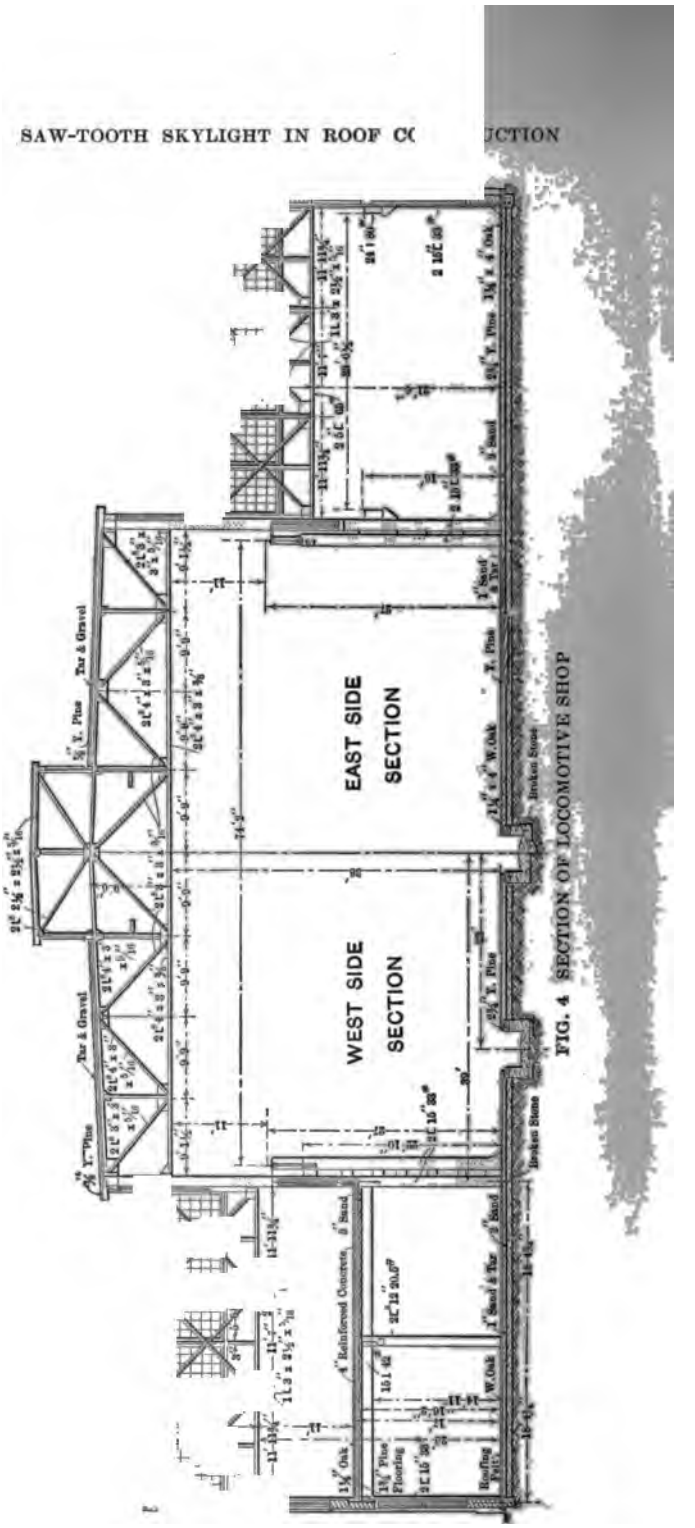


FIG. 4 SECTION OF LOCOMOTIVE SHOP

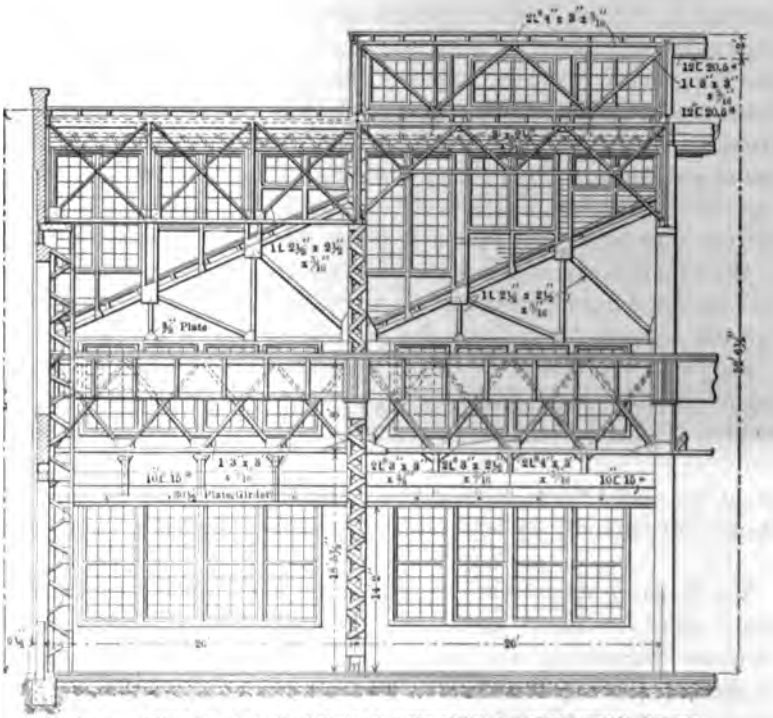


FIG. 5 ARTIAL LONGITUDINAL SECTION LOCOMOTIVE SHOP

they are located at the opposite side of the portion where the tiling is indicated.

2 In Fig. 4 a section of the building is shown in which it will be noticed that the saw-tooth windows are placed close to a horizontal truss. In designing this building to stand the heavy winds which exist upon the Western prairies, it was found that by utilizing this truss as a portal bracing, considerably less material was needed in the building than if this truss were omitted or disposed of in some other fashion. The depth of truss being 12 feet, it gives a very great amount of rigidity to the structure and at the same time lends itself very nicely to supporting the triangular trusses which appear in Fig. 5, the hypotenuse of which supports the tile roofing, and the vertical sides constitute the window face of the saw-tooth. Four triangular trusses are carried from these parallel trusses, one at each row of columns and one at each of the two middle apices. As the high end of the triangular truss is attached to one side of these parallel trusses, the top cord is properly stiffened and at the same time the lower cord of the triangular truss is designed so that shafting timbers, etc., could be suspended from it, making not only a rigid roof construction, but a suitable support for shafting.

3 This construction, we think works out much better in a building of this sort than if the skylight windows were inclined. The windows can also be made in the form of ordinary glazed sash, thereby reducing the cost and decreasing the danger of leakage and enabling us at the same time to construct a building of great stiffness and transverse strength, without interfering with the lighting qualities.

MR. SAMUEL M. GREEN Mr. Hinds has not brought out in sufficient relief to be of use to one first attacking the problem, the troubles pertaining to saw-tooth skylights. I shall attempt to show in the following what these troubles are, to point out some of the faults of Mr. Hind's design, and describe what I consider the best methods and details of design to meet these troubles.

2 In all my remarks I refer only to the saw-tooth roof as used in the textile industries, as the requirements in this field are far more exacting than in any other.

3 The excellent lighting qualities of the saw-tooth skylight are well known to those who have had experience with it, but the person who has never been in a building properly lighted by this method has a surprise in store, as north light has a very penetrating power and under it, imperfections of surface or texture are readily discerned.

4 The advantages of the saw-tooth form of skylight lighting over the ordinary skylight depend entirely upon the requirements of each case. If either north light is desirable, or the direct rays of the sun are objectionable, or as usually happens, both requirements exist together, then the saw-tooth is the only solution of

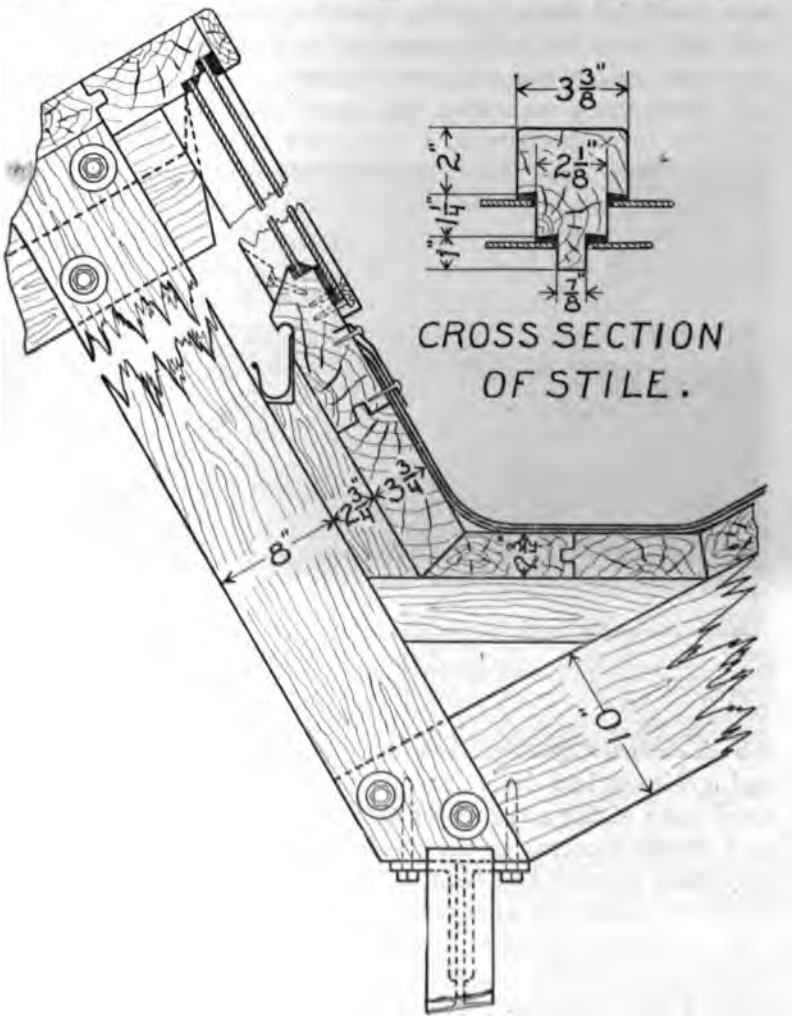


FIG. 1 CROSS SECTION OF GUTTER

the problem. But if these requirements do not exist, then I think the skylight of the ordinary form is preferable.

5 Practically all the troubles of the saw-tooth skylight are caused by severe winter weather conditions of our northern climate, and

can be classed under two heads: leaks caused by severe outside conditions, and inside condensation caused by low outside temperatures.

6 Rain, of course, will find any ordinary hole or crevice. Snow and ice cause water to back up and find imperfections that otherwise would not cause trouble. Snow and ice will freeze on to the roof and cause the roofing material to pull and sag. Frost will get under nail heads and pull the nails out.

7 Recently, in connection with my work for a prominent woolen company in Massachusetts, I was called upon to design a weave shed for 900 looms. This concern already had in operation a large shed, which I am informed was the first saw-tooth weave shed built in this country. It was of the English type and possessed all its faults, except as they had been partly cured by the mill management.

FIG. 2 EXTERIOR OF TEXTILE MILL, SHOWING SAW-TOOTH SKYLIGHT ROOF CONSTRUCTION

8 The first move I made was to see what other mill engineers and architects had done. During severe winter weather I investigated some of the more recent sheds belonging to the most prominent textile concerns in the north, and I must say I found that very little progress had been made to get at the real cause of the many difficulties and annoyances from the saw-tooth construction.

9 Evidently architects had not had practical experience in the maintenance of their designs and had not benefited by their failures. I was, however, connected with a superintendent who had for years carefully noted the troubles, and had made strenuous efforts to overcome them, and it was largely due to his suggestions that I was enabled to design a roof that I believe practically meets all the difficulties.

10 In Mr. Hinds' paper, Par. 8 and 9, the concern previously

referred to, built as early as 1880 what Mr. Hinds calls the Americanized type, which consists, as I understand it, of a flat gutter instead of a rounding one.

11 (Par. 11) To explain more fully the troubles of the metal gutter, the test of the English type of gutter, and in fact any other design, is winter weather. Changing temperatures cause the metal to expand and contract until it breaks and then leaks. The worst condition with snow is when it melts, then freezes, and then melts again under the ice, thus causing the water to back up hill,

FIG. 3 INTERIOR OF MILL, SHOWING SAW-TOOTH SKYLIGHT AND PIPING PROTECTED BY GALVANIZED IRON SHIELD

as it were. This water will discover any aperture at cap flashing on the glass side, or between the metal gutter and roofing material, on the other side.

12 In our northern climate the sharp gutter was found impossible at once by all the first users of it, and the change to a flat gutter roofed with the regular roofing material, was made simultaneously by several companies.

13 The company mentioned, as early as 1880, built an addition, using the wide flat gutter. The old roofs that they first had were covered with slate on the flat side. This they removed and replaced

FIG. 4 INTERIOR VIEW OF SAW-TOOTH SKYLIGHT SHOWING CONSTRUCTION OF VENTILATOR DAMPERS

at various times with many kinds of prepared roofing material, all of which failed.

14 (Par. 12 and 15) Too much pitch to the gutter is not possible. One-half inch per foot is none too large but usually is all that can be reasonably obtained. It is a mistake to try to carry all the water to the end of the skylight or gutter. It is better to put in an ample number of down-takes for the roof water, at intervals along the length, carrying them down inside the building.

15 (Par. 13) A 60 degree angle of glass I have found highly satisfactory in the North. I have never experienced any trouble from the direct rays of sunlight, especially if factory ribbed glass is used. In this connection, the angle at the ridge of the roof should be 90 degrees or more, in order that the light will not be thrown against the inside of the roof. I would not hesitate to make the angle of the glass 55 degrees and that of the ridge 95 degrees.

16 (Par. 17 and 18) The elimination of all cross beams that cast shadows is a necessity in textile work and can always be done by using sufficient posts, if the requirements will allow. The use of a rod for the lower member of the truss, in place of a beam, is a good idea, although this beam does not interfere with as much light as a beam running parallel with the roof.

17 (Par. 19 and 22) In the North, double glazing, on account of its better heat non-conducting qualities, is preferable to the single. The only serious objection is the difficulty of repair.

18 These paragraphs refer to the greatest weaknesses of the design described by Mr. Hinds. He passes lightly over the problem of condensation. In textile work a high degree of humidity is maintained, with the result that in cold weather condensation on the glass is very great. This is especially objectionable in a weave shed, for the reason that even a drop of water on a sized warp will cause exceedingly bad work. The objection to Mr. Hinds' method of taking care of this condensation is that the holes he provides for letting this water outside will collect an icicle and freeze, with the result that the gutter fills and runs over into the room. These holes also allow a large amount of cold air to leak into the room. The proper method is to remove this water by means of inside gutters.

19 To determine the value of one of the much advertised forms of metal-bar skylights, for saw-tooth work, I installed a small section, with the result that the lower ends of the bars, on the inside, were covered with very heavy frost and the aperture to allow the water of condensation to escape froze up. Of course these faults barred the design from consideration.

20 The principal advantage of the metal construction over wood is the ease of installation. Its disadvantages follow: Metal is a better conductor of heat, therefore causes condensation. Particularly the upper and lower horizontal members of the metal skylight, on account of coming in contact with both the outside and inside air, are a very great source of annoyance, through becoming condensers.

21 The horizontal members are long, are therefore badly affected by expansion and contraction, and it is difficult to make a satisfactory joint between the lower horizontal member of the skylight and the gutter construction. Mr. Hinds' method is entirely

FIG. 5 SHOWING ROOF AND COVERING OF SAW-TOOTH SKYLIGHTS

inadequate, as water, in the event of snow filling the gutter, will certainly back up through any counter and bottom metal flashed joint that can be made.

22 (Par. 23) The slat walk must have a bad wearing effect on the roofing and in a way defeat its purpose, in that it holds the snow and ice and prevents its rapid melting. The supports for the walk will hold moisture and cause decay, both in the supports and in the roofing.

23 The better method is to make the roof good enough so it can be walked on, and also so that snow will not have to be removed except

in case of a blizzard, in which case a board walk will not prevent damage from shovels.

24 (Par. 34) The fact that wood sash are being removed in some places and metal sash substituted only indicates that the owners have been convinced that their troubles are going to be cured by the substitution. I am inclined to think that their troubles will be augmented.

25 The design described in the following has proved almost faultless to date.

26 It will be observed from the accompanying illustrations that the building is of semi-steel construction; the posts are steel I-beams, being anchored to concrete piers, and extend in one piece from piers to roof. The wood floor beams rest on, and are bolted to, I-beam stringers, the stringers in turn being riveted to the posts. The floor planks are 4 inches thick, thoroughly spiked to floor beams, and at the wall ends are bolted to steel angles, which in turn are bolted to the brick walls. This construction makes the floor very firm, and at the same time sufficiently elastic for high speed heavy looms.

27 The tying together of the roof and the posts is accomplished by light steel channels and angles, which form the shafting supports. The usual method for belting looms is from below the floor; in fact, it is absolutely necessary to so belt them for some classes of goods. The method causes less obstruction of light, but when possible, I think the advantages of the overhead belting over the under-floor belting, more than equal the disadvantages.

28 Fig. 1 is a detail of gutter, glass, and ridge construction. The pitch of the gutter is made by light cross pieces on top of the roof timbers. The curb is of 4 inch pine, the top of which is beveled at a sharp angle, to permit the water of condensation to readily run off the curb, and it is also grooved to form a drip edge for the water to drip into a small copper gutter, which gutter is connected by means of a lead pipe to the regular roof down-take.

29 The gutter proper is made as follows: The corners formed between the bottom of the gutter and the curb on one side, and the gutter and the flat roof on the other, are filled with a fillet of wood of curved shape. Then sheet asbestos, $\frac{1}{16}$ inch thick, is laid, extending up to within 3 inches of the glass on one side, and 2 feet on the flat roof on the other side. On this asbestos is then laid galvanized iron of about No. 24 gage, extending to the same heights. This galvanized iron is nailed down. The object of it is to make the gutter firm to walk upon and to cover up any imperfections in the plank, especially as when the plank shrinks it will cover up the

cracks, thus preventing the felt being broken when walked upon. The asbestos prevents moisture from the room reaching the galvanized iron, condensing, and dripping back into the room.

30 After the gutter is so prepared it is then ready to receive the regular five-ply asphalt or pitch roofing. It is well to lay an extra ply in the gutter, to increase the strength. The roofing should be thoroughly nailed and mopped. On the glass side, it should be brought up to within about 2 inches of the glass. To protect this edge of the roofing, a flashing of galvanized iron was used, the edge of which was bent and sharpened and then driven into a cut in the curbing made by a special tool, shaped like a calking tool. Then it was nailed, with 1 inch spacing of nails, at the top and bottom. Slag, on account of its lightness and porosity, and consequent better holding qualities, was used to cover the gutter and flat portion of the roof. The curbing under the glass was thoroughly mopped, up to the glass.

31 The stiles or bars were made of white pine, firmly fastened to curb and ridge with brass screws. Both curbing and stiles were shellaced inside and out before painting. The painting throughout was with pure white lead and oil.

32 The glazing was double, the inside light being $\frac{1}{4}$ inch factory ribbed and the outside being plain double-thick glass. The outside glass was held from slipping downward by means of brass screws. Both lights were thoroughly puttied with 33 per cent white lead putty.

DRAINAGE

33 Roof down-takes were spaced about sixty feet apart to enable the gutters to empty themselves quickly. The down-takes are 4 inch copper pipes, carried down to the basement floor within the building posts, the posts for the down-take pipes being of a "built-up" channel section, whereas the regular posts are I-beams.

34 To prevent condensation, the copper roof bowl was covered with plastic magnesia and the down-take pipes were wrapped with asbestos. This piping was protected from damage by means of a galvanized iron shield seen on the first post to the left in Fig. 3.

VENTILATION AND HEATING

35 A weave room, especially for wool, should be thoroughly ventilated, first, to give healthful conditions, and second, to give even humidity throughout the room. In this room ventilation

was accomplished by means of two steel plate blowers, each driven by a motor, the entire equipment being located in the basement. Their combined capacity being equal to a ten minute air change.

36 It was so arranged that air could be drawn either from out of doors or from the basement, and air could be cooled by coming in contact with artesian well water. The air is discharged into the room in fifteen places, at a height of about 8 feet above the floor line, and is allowed to leave the room by means of innumerable openings near the floor line, into the basement, by four revolving ventilators in each saw tooth and by the windows. These arrangements permit all fresh air to be used or all foul air or any mixture of the two desired.

37 Roof ventilators have been a source of great annoyance on account of the condensation that occurs inside them and the difficulty of making them tight at the roof line. To prevent the former, both the stationary parts of the revolving elbow were double walled, making 1 inch air spaces. To care for the latter, the roof joint was made tight with a copper flashing, the flat portion of which was large in area and was placed before the roofing was laid. The upper edge of the circular portion of the flashing was hammered over and soldered to the top edge of the stationary part of the cowl.

38 To close the ventilators, a damper of special design was made, which hermetically seals them. The construction of this damper is plainly shown in figure 4. It is nothing more or less than a stopper having a soft packing and controlled by a lever and rope. The connection between the rope and lever is by means of a spring so that there is a constant pressure exerted against the packing.

39 This damper has not been entirely satisfactory, for the air will work its way through the packing, condense in it, and drip back.

40 Heating is by direct radiation, two thirds of the pipes being on the wall near the floor, and the balance at the ceiling. For some unaccountable reason, indirect heating has been much used for recent weave shed work but I have yet to see an indirect system that was satisfactory and economical. In my investigation I did not find one mill manager or superintendent who was at all satisfied with his indirect system.

SUMMARY

41 The lighting qualities of the saw-tooth roof skylight cannot be improved upon. Progress has been extremely slow to improve

the mechanical defects of this skylight. The [illegible]n points of the design I have submitted are:

a Careful gutter design and construction to prevent leaks.

b No metallic connection between inside and outside air; therefore no uncontrolled condensation.

c Careful provision to remove the water of condensation on the glass.

d No uncontrolled openings between the inside and outside, which let in cold air.

e Minimum obstruction of light.

f The use of factory ribbed glass, which diffuses the light so that what slight obstruction there is becomes unnoticeable.

42 Referring to Professor Sweet's discussion, I doubt not that the design used at the Straight Line shops is satisfactory for a machine shop, but I am very sure that it would not answer for textile work on account of the condensation on the cast iron gutters.

43 I should like to know just the exact detail that was used by Professor Sweet to prevent leaks in the joints between this gutter and flashing on one side, and roof on the other side.

Mr. L. H. KUNHARDT What I may say in discussion of the papers presented on this subject is simply one of endorsement of the type. Even today the value of good light in manufacturing plants is not sufficiently appreciated, that is, sufficiently so as to force in every case an intelligent study of the conditions. In the ordinary factory type of two or more stories I can give many instances of plants recently built where the tops of the windows are from two to three feet below ceilings and pilasters nearly as wide as the windows, when there was no reason why the top of the sashes should not have been practically at the ceiling and the pilasters occupying less than one third the wall space, thus allowing wide windows.

2 The application of saw-tooth roofs ought to be more general, as the distribution of light is superior in every way, in fact it was stated to me in one case that on a dark day or toward evening, it even seemed lighter inside the shops than outside, probably due to the more uniformly diffused light and the absence of shadows.

3 As illustrating the growith of this type I have taken for example the manufacturing plants, 2044 in number, to the value of $1,500,000,000 insured by the Boston Manufacturers Mutual Fire Insurance Co. and the other Factory Mutual Companies associated with it. Of these, some old factories, some new, but most all

; extended more or less from time to time, 168, or over 8 per cent have one or more buildings with saw-tooth roofs. They are ed among the various stated, as noted in Table 1. The num- f these built since the beginning of 1900 is also given and it rth stating that, of the 70 built previous to 1900, 31 were built en 1895 and 1900, and nearly all of these after January 1,

TABLE I

osition of Saw-Tooth Roofs by States and Approximate Date of Erection

	NO. OF FACTORIES INSURED	NO. HAVING SAW-TOOTH ROOFS.	NO. HAVING SAW-TOOTH ROOFS PREVIOUS TO 1900.	NO. HAVING SAW-TOOTH ROOFS 1900–1906 INCL. TO DATE.
ı	90	2	0	2
.....	72	0		
ampshire	88	3	0	3
nt	24	2	2	0
husetts	502	22	5	17
Island.....	137	14	3	11
ticut	200	13	8	5
ork	277	15	5	10
rsey	146	29	16	13
lvania	250	43	28	15
ıre	12	1	0	1
nd	13	1	0	1
a	14	1	0	1
.....	61	6	2	4
ky	6	1	0	1
ın	17	2	0	12
ı	9	3	0	13
sin	19	1	0	11
.....	30	4	0	4
arolina	47	2	0	12
ı	12	1	1	10
ıa	13	1	0	1
see	5	1	0	1
	2044	168	70	98

the 70 before 1900: 6 were built between 1870–1880; 15 or 16 between 880; 15 or 16 between 1890–1895; 31 between 1895–1900, and nearly all 31 after January 1, 1898.

The growing favor with which these roofs are looked upon is ore evident, and it must be noted also that there are many such roofs on factories which we do not insure and of which not the data at hand.

5 In the effort to add to my own observations the experience of others, I communicated with many of the factories to learn of troubles or disadvantages, if any, and in general, practically all faults reported are either due to design or to faulty workmanship. As regards application, the testimony is almost uniformly favorable for weaving and similar processes in textile factories and for machine shop and similar work, such as assembling, drafting and in all places where best light is desired. In foundries and dye-houses there is more difference of opinion, but not sufficient to discourage their use, the main trouble being ventilation.

6 In general, the disadvantages are from leaks, poor ventilation, excessive heat, and condensation when roofs are of thin boards, or excessive condensation when rooms have considerable moisture in them, all of which can be obviated. I will give a few suggestions:

a Do not build the stories too low. Twelve to fourteen feet under the girders is in my judgment a minimum, and more is needed under many conditions. While a low story brings the glass and the light down nearer the work and makes less space to heat in winter, on the other hand the ventilation is distinctly poorer and the heat of summer more oppressive, due to the sun's rays directly on the sloping roof planks which are so near the heads of the employees.

b Design the saw-teeth to face the north, directly or not more than a few degrees to the east of north, as the morning sun for a short time is not so objectionable as the afternoon sun.

It is desirable to exclude direct rays of sun whenever possible. The saw-teeth can be placed to run diagonally on a building if it is necessary.

c Ventilation by a fan system is to be preferred, as otherwise the middle of these wide buildings do not get fresh air. Excellent results are obtained in weaving rooms having fans in dry basements taking the air from the basement and through windows and discharging it over the heating coils to the floor above. Metal ventilators of ample area at frequent intervals along the top of each saw-tooth are to be preferred to other methods of top ventilation, and these, in connection with the fans, will remove sufficient air to keep the atmosphere pure. I do not think ventilators alone are sufficient

in these wide buildings; something is needed to keep the air moving. A combination of the fan system with direct heat may perhaps give best results. Pivoted or swinging sashes are apt to give trouble from leakage in driving storms, and dirt also blows in through them when open. In foundries and wet rooms very ample ventilation areas and good height are necessary.

d Leaks are a common fault, but can be overcome by maintaining a flat gravelled space of from one to not over two feet between saw-teeth, and by flashing high and insisting on good workmanship and materials. Continuous saw-teeth have less chance for leakage than a number of short ones, but on the other hand, when they run longitudinally on a long building they need to be broken up at intervals to allow access across roof for removal of snow in severe storms or for fire. By bringing saw-teeth to the side walls and extending the side walls up, the side windows become unnecessary and there are then absolutely no shadows. Condensation gutters with provision for carrying water outside have been obstructed by freezing if not properly designed therefor, and are sometimes drained to a point inside the building. The bottom of the sash should be horizontal and not follow the slope of the roof.

e Galvanized iron sash I think are to be preferred to wood, as they are stiffer, the putty does not come out as in wood sash and the sash does not rot as any wood sash is inclined to do, especially when not vertical. All galvanized iron is, however, poor at its best and paint has to be depended upon to prevent rusting out. On this point practice varies. Wood sash is, of course, cheaper in first cost.

f Ribbed glass is to be preferred with ribs vertical and on the inside. The sloping glass in saw teeth probably keeps cleaner under the same conditions, both inside and outside, than vertical glass in the ordinary monitor roof.

g Saw-tooth roofs cost more but not so much more that the added expense is not fully warranted for all rooms where excellent light, well diffused, is to be desired. The cost of artificial lighting under ordinary monitor roofs or in rooms with side windows only is con-

siderably more, due to the larger number of hours such light is required, and this is a fixed charge. As one man expresses it, he has "more light at less cost" under his saw-tooth roof.

h Roofs should be built of plank not less than 3 inches in thickness on wide bays—timbers 8 feet to 10 feet on centers. The light purlins or joists on heavy trusses 20 feet or more on centers ordinarily present no advantages over lighter trusses 8 to 10 feet on centers with plank spiked directly to them. The smooth roofs overhead are in every way the best. Hollow spaces in roofs are not necessary and only a very few factories have them; their use is not justified and the roof is, I believe, distinctly poorer. A good thick roof is cooler in summer and requires much less heat in winter than a thin one, perhaps more than a hollow one, but not, I think, enough more to make the use of concealed spaces advisable when considering their undesirable features.

I also present a table showing the disposition of these roofs over various processes in the 168 plants noted in Table 1.

7 I wish to add a word regarding fire protection. It is a recognized fact that roofs that have any wood about them in their construction will burn, as noted in the paper presented to this meeting by Mr. Alexander Brown of the Brown Hoisting Machinery Company, and we might add a very considerable list of similar experiences to his. It is also a recognized fact that any occupancy of a plant which involves use of contents, combustibles in themselves, may involve at least partial destruction of buildings built practically of incombustible construction. Hence one of the fundamental principles should be to provide protection ample for each individual case. In this way can be obtained extremely low cost insurance on industrial plants, which is and has for ten years with us been averaging from seven to eight cents per $100 of insurance and is just now less than this, and for the so-called fire-proof buildings, which in most cases today are simply fire resisting, even these figures can be reduced.

8 I mention the question of cost of insurance especially of the latter type, as I believe it was stated a year ago at our meeting that insurance of these costs 30 cents, and I wish to urge upon all not to expect the building to protect the contents, but rather to provide protection commensurate with the risk, and obtain rates which make

ible more than a good return on the additional investment, and ıe same time make interruption or loss of business, which is more ensive than anything else, practically an impossibility. Nothing yet or ever will equal the automatic sprinkler device for extin-

TABLE 2

Disposition of Saw-Tooth Roofs Over Various Manufacturing Processes

	TEXTILE						MET. WORKERS			MISC. IND'L. PLTS				
	WEAVING, WINDING, ETC.			MISCELLANEOUS PROCESSES	BLEACH OR DYE WORKS		MACHINERY	FOUNDRY	MISCELLANEOUS	SOAP	LITHOGRAPHING, PRINTING	PAPER COATING	OFFICES, DRAFTING OR ENGRAVING	OTHERS
	COT.	WOOL	SILK		COT.	SILK								
s							1	1		1				
lampshire					2		1							
nt	1	1												
chusetts	15			6			3							
Island	6	2	1		4			1						
ticut	7		3	3	1		3		1					
ork	1						7	5	1		2	1	2	
rsey	2	4	10	4		7	4	1	1				4	1
lvania	4	12	14	2			8	2			1			
are							1							
and			1											
a	1													
			1	1			2	2					1	
cky								1						
an							1							1
a							1	1						1
							2							1
nsin														2
rn States	5							1						
l	42	19	30	16	7	7	34	15	3	1	3	1	7	6

he total of 190 varies from total of Table 1, due to some of the plants having various covering distinctly different processes.

ıing fires, and I close these remarks with the oft repeated re to "put in a thorough equipment of automatic sprinklers orced by adequate water supplies." You then have an ever nt watchman always working in your interests.

MR. W. B. SNOW An additional feature in the design of the roof of the B. F. Sturtevant Company's machine shop should be noted. The shop, which is of the gallery type, is 120 feet wide with a central craneway 40 feet wide. The transverse saw-tooth skylights are 60 feet long; that is, they overreach the gallery floors by 10 feet. Immediately beneath this overreach on either side runs a bench which, because of the excellent lighting, is very generally utilized for fitting and similar work. In fact, this is one of the most important features of this particular application of the saw-tooth. It is unfortunate that through the combination of short exposure for the photograph, a poor halftone and the dark-colored background, the lower portion of Fig. 8 suggests extremely poor lighting. From Fig. 9, which shows the other side of the crane girded, the true value of the lighting is evident.

2 No ventilators were provided for these skylights. A little calculation will at once show the relatively slight air movement created through such devices when the temperature difference between indoors and out is as slight as that which occurs in midsummer. Naturally the best ventilation results when least needed, namely, in midwinter. Much larger areas or positive-acting fans are necessary to secure a movement adequate for increasing the comfort on summer days.

3 Actual experience has shown no great discomfort existing in the gallery of this shop, as compared with that in the third floor of a parallel shop, which has a roof of ordinary mill construction without skylights.

4 There is evidently an error in Mr. Hind's statements made in paragraphs 34 and 35, which would indicate that the skylights shown in Fig. 9 have been changed. Such is not the case.

THE AUTHOR If Mr. Henderson's discussion would apply to trusses on a span of 35 feet I would like to reply in connection with the point I have endeavored to emphasize and which also answers other discussion, that 24 inches to 48 inches in width between each skylight cannot consistently be called a gutter, but is really a flat roof. In designing a new shop, even in the Western states, I could introduce trusses four to five feet in depth and carry out the features which I have demonstrated. In fact, on an addition to the Mohawk Carpet Mills at Amsterdam, N. Y., I designed last year a saw-tooth skylight roof for the steaming and coloring departments where I introduced wood trusses in the middle of the flat space between

each skylight. That is, taking the place of the girder and form above same as shown in Fig. 3, and *starting the top chord* of truss at the roof plank. The span was only a matter of 28 feet, and for this I used wood rather than steel.

2 I would like to answer Professor Sweet's discussion, for the reason that he claims I made some mistake. Now, the first mistake that he makes in his own discussion is the statement that I claim to be the first to apply it to a machine shop. In my paper I refer to the use of it in lighting the area in a mill yard or textile mill and not a machine shop. Therefore, another man deserves the credit of first introducing this type of skylight on machine shops, and evidently from what he states its use is very satisfactory.

3 In discussing the other features, I will say that Professor Sweet's method, while a good one, would be more expensive than the other, and secondly, it does not provide for the matter of condensation, which in cast iron gutters and below the roof line would, with the low temperature outside, tend to condense even greater than if the flat space between the skylights was a part of the roof itself.

4 In the hanging of shafting to this form of roof construction, it is applied to a great variety of manufacturing plants—in some cases for lighting a room that has no shafting; in other cases where the skylight is presented to the north and across the shop or factory the shafting could be very readily supported, and has been done in a number of cases, by the simple method of using two wooden girders, or steel frames spanning the skylights at any point where the shafting lines cross them.

No. 1121

FERROINCLAVE ROOF CONSTRUCTION

By ALEXANDER E. BROWN, CLEVELAND, OHIO
Member of the Society

1 On December 17, 1900, the entire shops of The Brown Hoisting Machinery Company were destroyed by fire. This destruction was complete as to floors, as well as to roofs of the buildings. The fire started in the erecting, or assembling shop, which was constructed with brick walls and steel columns and roof trusses, the only wood being the roof purlins, which were 8 x 12 surfaced pine timbers on which surfaced, matched roof boards were secured. The roof proper consisted of the best slate laid on a covering of asbestos paper on the roof boards. All of the roof boards and purlins were painted with a so-called fire-proof paint. The floor of this, as well as of all of the rest of the buildings connected with it, were of three inch jointed plank laid on two feet of cinders on the ground.

2 All of the buildings were one-story construction, 50 feet high at the ridge, uniformly 100 feet wide and without galleries, which construction was considered by the insurance companies at the time as practically fire-proof and the lowest rate of insurance was accorded to it. A barrel of shellac varnish outside of the building, in a corrugated iron shed, suddenly caught fire, exploded, and blew in one of the outside windows of the erecting shop, carrying a volume of flame and gas into the upper part of the building next to the roof boards, which immediately caught fire and burned. The fire spread with such rapidity that the entire shop buildings, covering five acres, were completely destroyed in less than forty-five minutes. The roof itself, having caught from the under side, seemed to form an immense reverberatory furnace, as the floor of the building and all of its contents were burned from the reflected heat of the burning roof boards.

3 This building was considered by the insurance companies one of the best of manufacturing risks—but after the fire, the rates all over the United States were greatly increased on buildings of similar construction.

Presented at the New York meeting (December, 1906) of The American Society of Mechanical Engineers and forming part of Vol. 28 of the Transactions.

4 On account of the losses and detentions in business and the increased insurance risks, the company determined to rebuild the shops as nearly fire-proof as it was possible to design them. The entire structure of the building was determined on to be built of steel, and the walls possibly of brick or concrete; but the roof and floor were not determined upon until after the structural work had been commenced, assuming that a good fire-proof roof could easily be obtained at any time. It was found, however, that any good fire-proof construction in the way of roof covering that was in use at that time weighed from 30 to 45 pounds per square foot. It was found that this additional weight of roof covering over the weight of a good slate or gravel roof would add to the cost of the entire building in structural work necessary to hold up the same about $50,000; and for this reason I determined that not more than fifteen pounds per square foot of roof should be used for the covering on the ordinary spacing of purlins of about five feet centers.

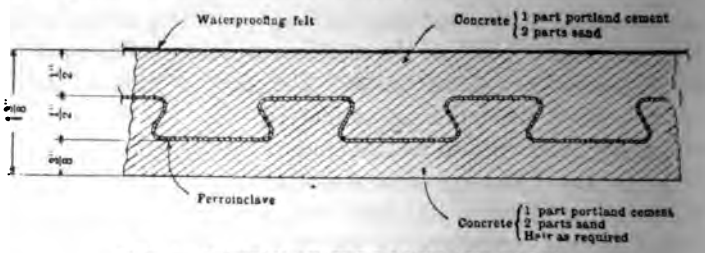


FIG. 1—SECTION OF FERROINCLAVE ROOF
AS USED ON SPAN 4' 10½" C. TO C. OF PURLINS

5 In my efforts to find a suitable roof of the proper strength within this weight and at the same time perfectly fire-proof, I felt that I would have to look to some form of cement steel construction. I soon determined that if it were possible to make, commercially, sheets with dovetail corrugations that could be put on to the roof purlins the same as corrugated iron, and afterwards cemented top and bottom with a mixture of Portland cement and sand, the requirements as to weight and strength would be obtained. After some time of study, I was fortunate enough to devise a method for quickly and cheaply forming dovetail corrugations in a sheet of steel. This, however, was at first with parallel sides to the corrugations, which I found would not do, as they would not telescope and lap over one another in shingle fashion at the ends to make them water-proof before putting cement on them.

6 Shortly after this I devised another method by which the corrugations were made wider at one end of the sheet than at the

other on one side, and the reverse on the other; that is, they were alternately wide and narrow on each end of the sheet, allowing either end to telescope into either end of its adjoining sheet, making them shingle perfectly on the roof and forming a perfectly water tight roof without cement. The sheets were made so that the laps on the sides as well as the end laps would interlock so as to be water-proof. After some experimenting, it was found that with No. 24 soft steel sheets with the dovetail corrugations filled with cement mortar, two parts of sand and one of Portland cement, top and bottom of the corrugations, so that the total thickness of the metal and cement was from $\frac{1}{4}''$ to

FIG. 2 METHOD OF APPLYING CEMENT

$1\frac{3}{8}''$, the weight did not exceed fifteen pounds per square foot, and that the strength, on 4′ $10\frac{1}{2}''$ centers between purlins was such that the covered sheets would sustain 60 pounds per square foot with a factor of safety of five. On tests made later on the same spans, 300 pounds per square foot just cracked the cement on the under side.

7 Ferroinclave, or iron in the form of dovetail, is the particular name by which this material is now known. After designing this material, on later investigations, I found that many attempts had been made in the past to utilize this very desirable form of corrugation for holding cement or other plastic material, both for shingles and other purposes, but all of them had been abandoned, apparently

on account of the costly or imperfect methods used for the production of the corrugations, and also because they could not be made to shingle in order to make the roof water-proof of itself.

8 In the Ferroinclave, adjacent dovetails or corrugations are wider in their reverse directions sideways, the depths of the corrugations thus being parallel and uniform. The depth of corrugations, as ordinarily used and found best for the purpose, is ½", and the sheets ordinarily are 10 feet long, and lay 20 inches wide on the roof. The laps on the purlins are usually three inches. The novel method of forming dovetail corrugations in sheet metal, as well as the article manufactured itself, known as Ferroinclave, were the subjects of patents obtained in this and various foreign countries.

9 In the use of the Ferroinclave, it is treated as the tension member, or bottom cord of the girder span it has to form, the cement only to act in compression.

10 The tables which follow of actual experiments made with No. 24 Ferroinclave sheets with different thicknesses of cement on top of same, with uniform thickness of cement on the under side, give center deflections for various loads up to the breaking load for each thickness of cement; and the diagram gives the thickness of cement required on top of the Ferroinclave sheets to produce ½ inch center deflection on spans of 4′ 10½″ for the different loadings per square foot shown.

11 The tests were all made upon sheets 20 inches wide, resting upon one inch square iron bars laid along the tops of I-beams and spaced 4 feet 10½ inches centers. All of the sheets were coated on the upper side with a mixture of two parts of sand to one part of Vulcanite cement and with a ⅜-inch mixture composed of two parts sand, one part cement and some hair below the corrugations on the under side. The sheets were then laid off into areas of one square foot each, and upon these areas were piled steel bars, so as to produce the given weight per square foot, as called for in the following tables. Deflection was taken at middle of sheet by means of a lever which multiplied the deflection eight times.

12 In comparing the diagram (Fig 3) with the actual tests made, it will be seen that where the curve starts on this diagram from the straight line, the thickness of sheet is not the most economical for the thickness of cement shown on the diagram beyond that point. A sheet of No. 22 Ferroinclave of five foot span covered with 4-inch cement over the top of corrugations, stood a breaking load of 3000 pounds per square foot, uniformly distributed, and is suitable for floors to be used up to 600 or 700 pounds per square foot. The gallery of the machinery floor of the Brown Hoisting Machinery Company's

works is of this thickness of construction, and is used even up to 800 or 900 pounds per square foot.

TEST A

Upper side of sheet filled with cement to a thickness of one inch above corrugations.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
54 pounds	$\frac{1}{16}$ inch	328 pounds	$\frac{7}{16}$ inch
136 pounds	$\frac{1}{8}$ inch	365 pounds	$\frac{3}{4}$ inch
221 pounds	$\frac{5}{16}$ inch	402 pounds	$\frac{7}{8}$ inch
256 pounds	$\frac{3}{8}$ inch	439 pounds	$1\frac{1}{16}$ inch
299 pounds	$\frac{1}{2}$ inch	476 pounds	$1\frac{1}{4}$ inch

Sheet failed during application of increased load.

TEST B

Upper side of sheet filled with cement to a thickness of $1\frac{1}{2}$ inches above corrugations.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
54 pounds	$\frac{1}{64}$ inch	402 pounds	$\frac{11}{32}$ inch
136 pounds	$\frac{1}{16}$ inch	439 pounds	$\frac{3}{8}$ inch
225 pounds	$\frac{1}{8}$ inch	476 pounds	$\frac{13}{32}$ inch
262 pounds	$\frac{3}{16}$ inch	513 pounds	$\frac{7}{16}$ inch
299 pounds	$\frac{7}{32}$ inch	550 pounds	$\frac{15}{16}$ inch
329 pounds	$\frac{19}{64}$ inch	587 pounds	$\frac{23}{32}$ inch
365 pounds	$\frac{9}{32}$ inch	624 pounds	$1\frac{5}{16}$ inch
660 pounds		failure	

This sheet broke in the center of one of the spans by tearing the iron.

TEST C

With two inches of cement above corrugation on upper side.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
54 pounds	0 inch	476 pounds	$\frac{7}{32}$ inch
136 pounds	$\frac{1}{32}$ inch	513 pounds	$\frac{1}{4}$ inch
225 pounds	$\frac{3}{32}$ inch	550 pounds	$\frac{9}{32}$ inch
262 pounds	$\frac{7}{64}$ inch	587 pounds	$\frac{5}{16}$ inch
299 pounds	$\frac{1}{8}$ inch	624 pounds	$\frac{3}{8}$ inch
329 pounds	$\frac{9}{64}$ inch	659 pounds	$\frac{27}{64}$ inch
365 pounds	$\frac{5}{32}$ inch	694 pounds	$\frac{1}{2}$ inch
402 pounds	$\frac{11}{64}$ inch	729 pounds	$\frac{5}{8}$ inch
439 pounds	$\frac{3}{16}$ inch	764 pounds	$1\frac{1}{4}$ inch
799 pounds		$1\frac{3}{8}$ inch	

This sheet failed by tearing the iron before the increased load could be put on.

TEST D

With 2½ inches of cement above corrugation on upper side.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
225 pounds	1/16 inch	900 pounds	11/32 inch
450 pounds	1/8 inch	1125 pounds	11/64 inch
675 pounds	11/64 inch	1350 pounds	failure

This sheet broke in the middle of the span by tearing the iron.

TEST E

With three inches of cement above corrugation on upper side of sheet.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
225 pounds	1/32 inch	1125 pounds	11/64 inch
450 pounds	1/16 inch	1350 pounds	3/16 inch
675 pounds	3/32 inch	1575 pounds	not taken
900 pounds	5/32 inch	1800 pounds	failure

This sheet broke in the center of the span by tearing the iron.

TEST F

With 3½ inches of cement above corrugation on upper side.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
225 pounds	1/32 inch	1125 pounds	5/32 inch
450 pounds	1/16 inch	1350 pounds	7/32 inch
675 pounds	3/32 inch	1575 pounds	11/64 inch
900 pounds	1/8 inch	1800 pounds	not taken
1975 pounds	failure		

This sheet broke in the middle of the span by the tearing of the iron.

TEST G

With four inches of cement above corrugation on the upper side.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
225 pounds	1/32 inch	1350 pounds	11/64 inch
450 pounds	1/16 inch	1575 pounds	5/16 inch
675 pounds	5/64 inch	1800 pounds	1/4 inch
900 pounds	7/64 inch	2025 pounds	1/2 inch
1125 pounds	9/64 inch	2200 pounds	failure

This sheet broke in the middle of the span by tearing of the iron.

TEST H

With $4\frac{1}{2}$ inches of cement above corrugation on the upper side.

Load per Square Foot	Total Deflection	Load per Square Foot	Total Deflection
225 pounds	$\frac{7}{64}$ inch	1800 pounds	$\frac{5}{16}$ inch
350 pounds	$\frac{1}{8}$ inch	2025 pounds	$\frac{3}{4}$ inch
575 pounds	$\frac{3}{16}$ inch	2200 pounds	not taken
2375 pounds	failure		

Sheet broke in center of span by tearing the iron.

FIG. 3 CURVE OF UNIFORMLY DISTRIBUTED LOADS

Per square foot, producing ½-inch deflection on a 4 foot 10½-inch span of No. 24 Ferroinclave, painted; then coated with cement, mortar and plaster. Time of setting, 14 days. Width of test pieces, 20 inches. 2 spans. Thickness of cement above Ferroinclave (2 sand to 1 Vulcanite cement). ½-inch wall plaster (gypsum) below Ferroinclave

13 On account of the uniform strength of even the thin slabs of Ferroinclave, when cemented, it is possible to construct steel buildings with purlins spaced the most economical distances apart, and its low weight per square foot of roof keeps the material required in the structure of the buildings itself and the purlins down to the lowest limit of any possible form of fire-proof construction. No wooden forms, or moulds, are required for the application of the Ferroinclave or the cement to the same, and in that way a large saving, both in time and money, is effected in applying it to the roof.

14 The sheets ordinarily do not rest directly upon the purlins, but instead rest on a $\frac{3}{8}$" square strip of iron, or hardwood, in the middle of the purlin. This space between the purlin and the lower edge

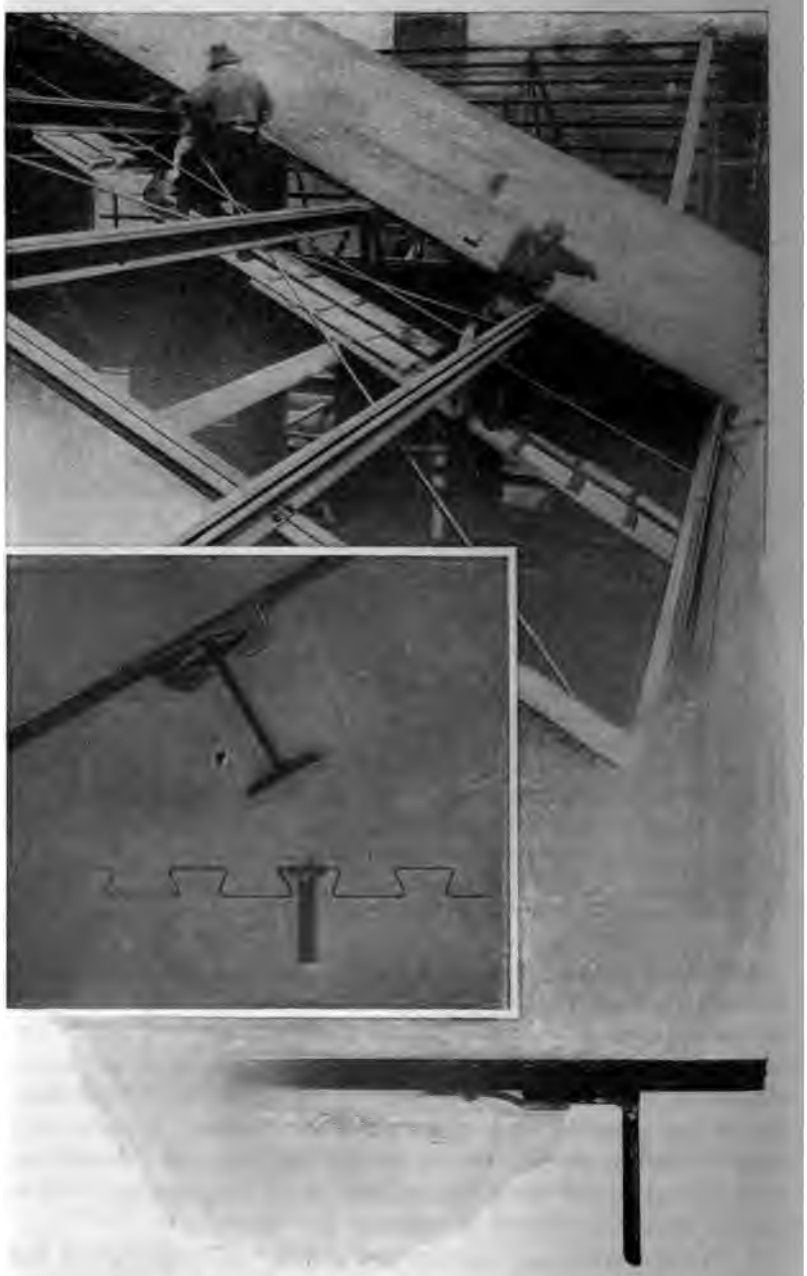


FIG. 4 FERROINCLAVE ROOFING AND SIDING

of the Ferroinclave is filled up with cement when the under side is cemented, thus keeping the steel clear of the purlin itself, or entirely air-tight and weather-tight in the cement itself, preventing any deterioration from exposure. From tests made, these sheets after being covered and in use for a term of years show no deterioration where they are covered only $\frac{3}{8}$" above and below the corrugations with a mixture of one part of cement to two of sand.

15 In many cases, on account of imperfect roof structural work, both as to alignment and as to solidity against initial springing and movement of its parts when the building is in use, the cement, after

FIG. 5 ROOFS WITH FERROINCLAVE IN PLACE READY FOR CEMENTING

being placed on the Ferroinclave on the roof, will sometimes develop cracks, due to separating it before it has become perfectly set. These cracks show up only after the cement has hardened. In such cases it has been found best to guard against any deterioration of the roof that may be due to leakage through these cracks to the sheet metal after the roof is finished and thoroughly dried and hardened, by covering the same with a thin covering of asbestos covering, or other similar good roofing material, stuck on with the proper consistency of asphalt.

16 The Ferroinclave sheet, owing to the form of its corrugations, lends itself admirably to forming into almost any shapes desired,

without distortion of the straightness of the corrugations or the width of the plate itself. It may be bent squarely across the corrugations without widening the sheet, as well as bent diagonally. The sheets may be rolled into any curve after they are in the form of the Ferroinclave as readily as any solid plate, by simply passing them through the bending rolls. This makes it possible to use the sheets for the forming of cornices, arches, and any ornamental work that may be desired to be used in conjunction with the regular construction and where the whole is to be covered with cement. It is particularly adapted to the construction of the risers and treads of stairways and

FIG. 6 ROOF CEMENTED FOR WATERPROOF COVERING

steps. Excellent fire-proof bins have been constructed with it, both in the ordinary flat structural form as well as the suspended type, the Ferroinclave sheets spanning from suspension strap to suspension strap to which they are riveted, and afterwards covered with the proper thickness of cement on top and the covering below to give the necessary strength. Floors for gas houses, as well as the coal bins for the same, have been very successfully constructed in this way of the Ferroinclave, and the fire resisting qualities, of course, are such as to be able to quench the coke directly on the floor.

17 Generally the cost per square foot of the Ferroinclave roof completed varies from twenty to twenty-four cents, according to the

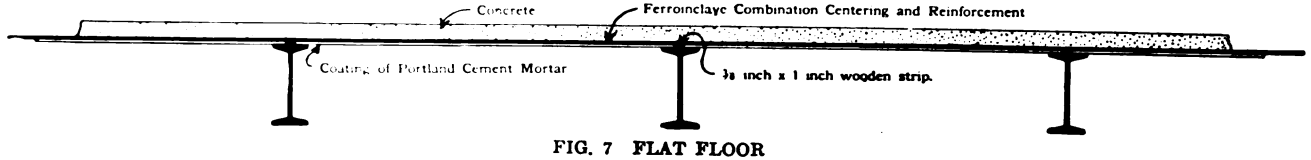


FIG. 7 FLAT FLOOR

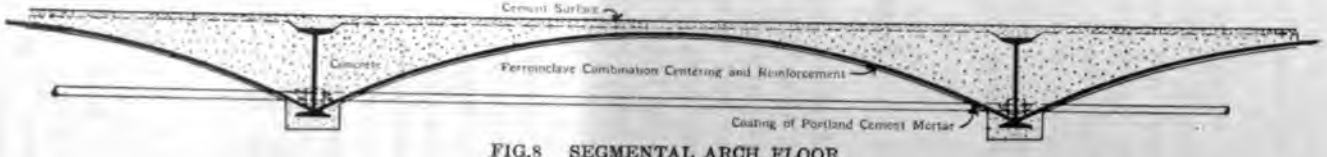


FIG.8 SEGMENTAL ARCH FLOOR

location and the cost of suitable Portland cement that is used in it. The saving of the additional structural material in the building itself that would be required for the heavier forms of fire-proof roofs, more than makes up for any reduced cost of such roof covering itself.

18 The Ferroinclave is equally applicable to the siding of the buildings and has been very successfully used for the purpose, particularly in large shop and warehouse constructions.

19 A good Portland cement, with a mixture of two parts of sand, after thoroughly setting, has about the same coëfficient of expansion as steel, and in consequence, when applied to the continuous sheet of Ferroinclave, the difference in temperature has little or no detrimental effect.

DISCUSSION

MR. EUGENE N. HUNTING The paper on fireproof roof construction as presented by Mr. Alex. E. Brown, setting forth the various merits of corrugated iron plastered with cement, brings before us a problem that nearly every engineer connected with the construction and maintenance of a manufacturing plant has to solve.

2 This problem has been worked out in about as many different ways as there have been engineers who have attempted it. Some of these solutions have had merit, and more have proved worthless after a test of time and the elements. Various combinations of asbestos and cement, sheet iron and cement, concrete reinforced with rods and concrete combined with tile, have been tried with indifferent success.

3 The writer has recently had occasion to go into the subject very thoroughly, both from a practical as well as a theoretical standpoint. After a careful examination of the many systems now in vogue, an outline of the modern requirements for a fireproof roof from the standpoint of the factory engineer was drawn up as follows:

a The roof shall not weigh over 25 pounds per square foot.

b The basis of the fireproofing material shall be Portland cement concrete.

c The concrete shall be suitably reinforced by placing steel in its theoretically proper position—near the lower side of the slab.

d This roof shall be constructed in such a manner that no wood form is necessary. In light roofs the expense of a form carried at the roof elevation and supported from the ground is prohibitive.

e The cost of this roof complete and in place shall not exceed 20 cents per square foot.

f The reinforcing metal shall be of such a nature that the concrete keys into it and, in case of expansion and contraction due to rapid rise and fall of temperature, the concrete will not crack.

4 Now let us consider for a moment the various constructions that have been placed upon the market for light roofs and see what are the principal objections to their general application.

5 Let us first look at the combination of asbestos and cement in the form of tile. This tile is very light—so light in fact that it has to be wired down to keep it on the roof. The attachments are susceptible to oxidation and the general scheme has not been sufficiently used to prove conclusively whether the combination will stand the test of the elements.

6 The next proposition that comes to mind is the light cement tile. This also has its limitations; it is hard to keep the roof dry and almost impossible to keep the shingles from cracking, both of which are due to changes in temperature.

7 Let us now consider the solution of the problem, as presented by Mr. Brown, by the use of Ferroinclave and see how it meets the requirements. It is light, cheap and easily applied. However, there are several points about it that do not appeal to an engineer—at least one that is familiar with the theories and methods of reinforced concrete designers.

a In the first place the sheet metal of Ferroinclave or Ferrolithic tile is not a true reinforcement for the concrete. The entire metal section lies very close to the neutral axis.

b There is no real key between the plaster and the metal except the interior angle of the metal.

c The writer could not conceive of Ferroinclave or Ferrolithic tile[1] acting much better than corrugated iron in a severe fire and water test.

8 It is quite evident to one familiar with the expansion of steel and concrete that in a severe fire the cement would spall from under the side of Ferrolithic tile. Also that on the application of water to the heated metal on the under side, the contraction of the metal would destroy all adhesion of the concrete and steel and the roof would fall.

The writer believes that Ferrolithic would [illegible] and serve its purpose when subjected to ordinary temperatures. However, in most cases it is not the small fire that we are trying to protect ourselves from—it is the fire that starts at one end of the plant and

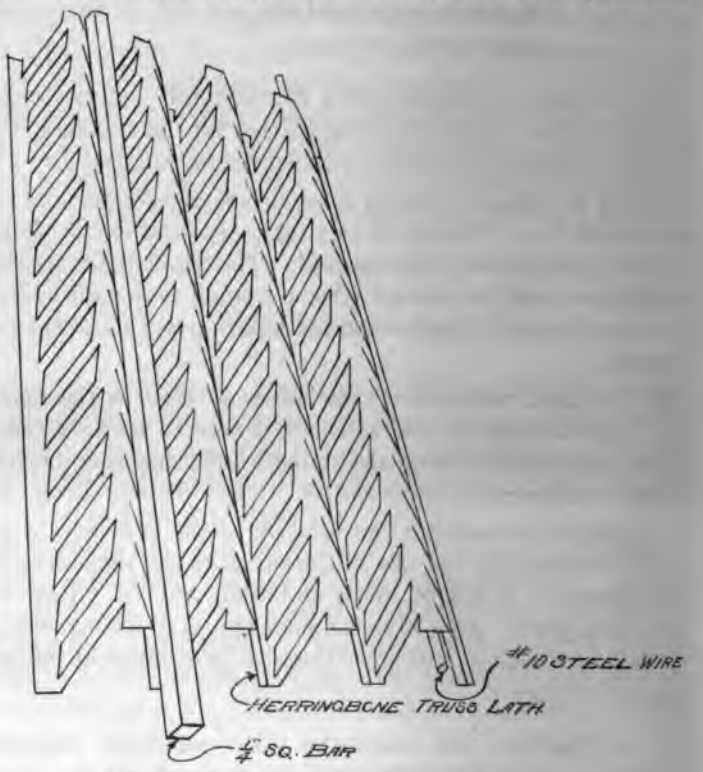


FIG. 1 HERRINGBONE TRUSS LATH

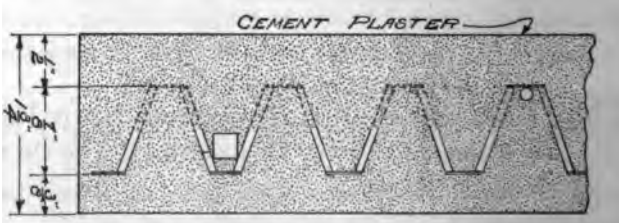


FIG 2 APPLICATION OF HERRINGBONE TRUSS LATH TO LIGHT FIREPROOF ROOF CONSTRUCTION

threatens to destroy all. This is the time when fireproof protection must be something more than a name or a theory; it must be true protection in a most serious conflagration.

9 The writer will endeavor to describe briefly in the following paragraphs a roof construction that he considers will meet every argument and give proper fire protection in every sense of the word.

10 Figs. 1 and 2 show "Herringbone Truss Lath" and its application to light fireproof roof construction.

11 The method of construction is very similar to Ferroinclave work. The lath is stretched from one purlin to another on small wires and is lapped at the joints. A coat of cement plaster is applied to the top and another to the bottom, the lath acting as a true reinforcement. This roof will carry all ordinary roof loads with a factor of safety of four on a three to four foot span. For heavier loads small iron rods are inserted running up and down the valleys of the Herringbone.

12 The cement mortar is thoroughly reinforced in both directions and has a perfect key. It can not spall when under severe fire and water tests because of the peculiar section of the metal. To substantiate this statement, the writer wishes to call attention to the fact that after the New York Building Department fire test on this material, examinations showed that the plaster was as securely locked in the key of the lath after the fire as before it was started. A heat of 1700° was maintained for two hours and the slab was subjected to fifty pounds of water pressure. There was no sign of cracking or movement of any kind—there could not have been a more severe test, nor could the result have been more satisfactory.

13 A remarkable feature, and one that appeals to the constructor as well as the engineer is the low unit cost of this construction. The cost of the roofing in place runs from 18 cents to 20 cents per square foot, depending upon the labor conditions.

14 The writer is of the firm opinion that in the near future practically all fireproof roof construction designed for light loads will be built on a self-centering, open reinforcement such as trussed Herringbone or its equivalent.

MR. B. N. BUMP Referring to Mr. Brown's paper on "Ferroinclave Roof Construction," I would like to ask Mr. Brown, if he has examined a section of the roof after it has been in service for several years. Not more than two years ago, a roof of such construction as Mr. Brown describes was put on a machine shop. A short time ago a heavy weight fell from above and broke through that roof, and on examination we found that the concrete or the sand and cement was in very good condition, but the iron was represented by a streak of rust only.

2 This leads us to wonder what is going to be the outcome of

other steel concrete construction, which is being used to a considerable extent.

THE AUTHOR Some of the statements in the discussion of my paper by Mr. Eugene N. Hunting seem to call for correction as they are evidently based on a lack of knowledge of what Ferroinclave actually is and does, and has done in practice, in the accomplishment of the object for which it was designed.

2 In the first place, I wish to correct the impression he evidently has and to say that Ferroinclave and Ferrolithic tile are not one and the same thing, neither are they constructed alike, nor act exactly alike when used in roof construction. He couples the two together in various parts of his discussion as though they were one and the same thing, and speaks of it as "Ferroinclave" or "Ferrolithic."

3 I believe my paper clearly shows that Ferroinclave is a true dovetail corrugation, having a well determined and proportioned key or lock in its form, which by reason of its width and depth, and the underlocking of the dovetail is best suited for holding the cement. The underlocking is about $\frac{1}{8}$ inch on each side, or nearly $\frac{1}{4}$ inch at the bottom of the corrugation wider than that at the top.

4 The most characteristic and important factor in Ferroinclave is the fact that the adjacent corrugations are tapered in inverse directions; that is, in a 10 foot sheet, the corrugation at one end is $\frac{3}{16}$ inch wider than at the other end, and the adjacent corrugation is the reverse.

5 In Mr. Hunting's discussion, under paragraph 7-a, he makes the statement that Ferroinclave is not a true reinforcement for the concrete, and that the entire metal section lies very close to the neutral axis.

6 This is evidently a mistake on his part, for there can be no more complete reinforcement than a continuous sheet of metal arranged to give a solid and perfect lock, or bond, in concrete cement. The outside dovetail action is continuous and solid, whereas any locking, by means of perforations only, depends on sharp edges and small portions to anchor in the concrete. It is absolutely impossible for the concrete to come out of these corrugations without being literally torn to pieces.

7 If Mr. Hunting had noticed the various tests which were made in actual practice of various sheets and thicknesses of concrete, he would have seen than when carried to breaking, the sheets invariably tore in two by mere tension, without the slightest effect of sliding of

concrete along the sheet. This has been proved by a great num- of tests under varying conditions.

Besides the adhesion, which can be secured by the metal itself, very form of the dovetail corrugation in its lengthwise direction, prevents horizontal shear, by reason of the tapers of the corruga- s in two directions; the material wedging as well as adhering.)ther words, the wedging action prevents horizontal shear, even)re breaking of adhesion could occur. Besides, the continuous esion throughout the entire length of the sheet makes a far more 'ect bond than intermediate notches or open spaces, where the ımulation, through the sheet itself, of small increments of adhesion always applied in the concrete at the point of breaking.

The other part of paragraph 7-a, in which it is stated as an :ction that the entire metal section lies very close to the neutral , is also a mistake, and would not have been made if Ferroinclave been carefully examined.

) In my paper I have stated that the depth of the corrugations ll cases is slightly under ½ inch, and that only enough cement on underside is put on to cover the lower surface of metal up to ⅜ ı; this is done even in floor construction, where the total cement is as much as five inches thick.

1 The central line of the Ferroinclave when in place, therefore, is er more than ⅝ inch from the bottom of the lowest portion of the ter. The very form of the dovetail corrugations gets the maxi- n amount of metal possible near the bottom to form the bottom :d of the concrete steel beam of which it is a part.

2 Samples of Ferrolithic sheets that I have seen and examined oughly have parallel corrugations, and the dovetailing or key :t is so slight, or the interior angle so small, and the spaces so wide, , it is probable there would be great difficulty in securing a perfect d or lock of the cement, particularly on the underside; whereas, the rior key and the horizontal taper of the Ferroinclave is so decided, the spaces so proportioned, that it is nearly a theoretical proper)ortion for locking the plaster. In the same paragraph "*c*" is I)ose only a supposition without experience on the part of the er, as a large number of fire tests have been made with the Ferro- ıve in about 5 foot spans, the same as is ordinarily used in roof ıstruction, where the span has been loaded at the same time to e than double its ordinary working loads; the whole sheet and s being heated to a white heat, and left to stand for some time, n water was thrown on it with full pressure through the hose, and er these conditions loads were dropped on the already loaded

beam. After this test there were found to be no signs whatever of the cracking of the cement away from the sheet, the only effect being slight hair cracks in the cement itself on the under surface. The cement was not in any way broken loose from the metal. In other words, it is impossible for the cement under these conditions, to break loose from the dovetail as proportioned in Ferroinclave.

13 There seems to be an impression, also in the discussion of this article, that in the heating and cooling of Ferroinclave, with its cement and sand covering there would be a great difference in expansion between the metal and the cement itself. On the contrary, the coefficient of expansion of good Portland cement and steel are almost absolutely the same, and the mixture of two parts of sand to one of good Portland cement is so nearly the same that under the conditions described they act together.

14 I am pleased to answer Mr. B. N. Bump's inquiry as to the permanency of Ferroinclave as used in roof or floor construction. When two parts of sand and one of good Portland cement are properly applied to the Ferroinclave sheets, the sheet itself will last indefinitely; the only chance of corrosion of the sheets in any way is by accidental cracks, and then corrosion will occur only at or near the cracks.

15 This has been determined by many trials and examinations of roofs that have been in use for nearly five years; and in fact, we have made several exceedingly severe tests for determining this very thing; one of them, particularly, where the cemented sheets were subjected to nearly a flood of water all the time, and in another case where the cemented sheets were in water all the time for over a year and a half, and when the cement was cut off, the iron was as clean and free from rust as when first rolled.

16 To avoid the possibility of any bad effects or cracks, due to improper roof construction after the Ferroinclave and cement has been erected, a waterproof covering of some form is applied, which is elastic enough to span over any small cracks that are due to motion that may be in the imperfect construction of the roof of the building.

17 With three or four roofs that were put on when Ferroinclave was first designed, we used gypsum plaster on the under side instead of cement. The sulphur which the gypsum contained while it was still damp, caused chemical action upon the metal and sometime after, by the porosity of the gypsum which absorbed further moisture, corroded the sheets more or less. By the swelling of the oxide products from this chemical action, some of the plaster was found to come off where exposure to dampness on the underside was the greatest. This occured on the first roof where Ferroinclave was used, but since that

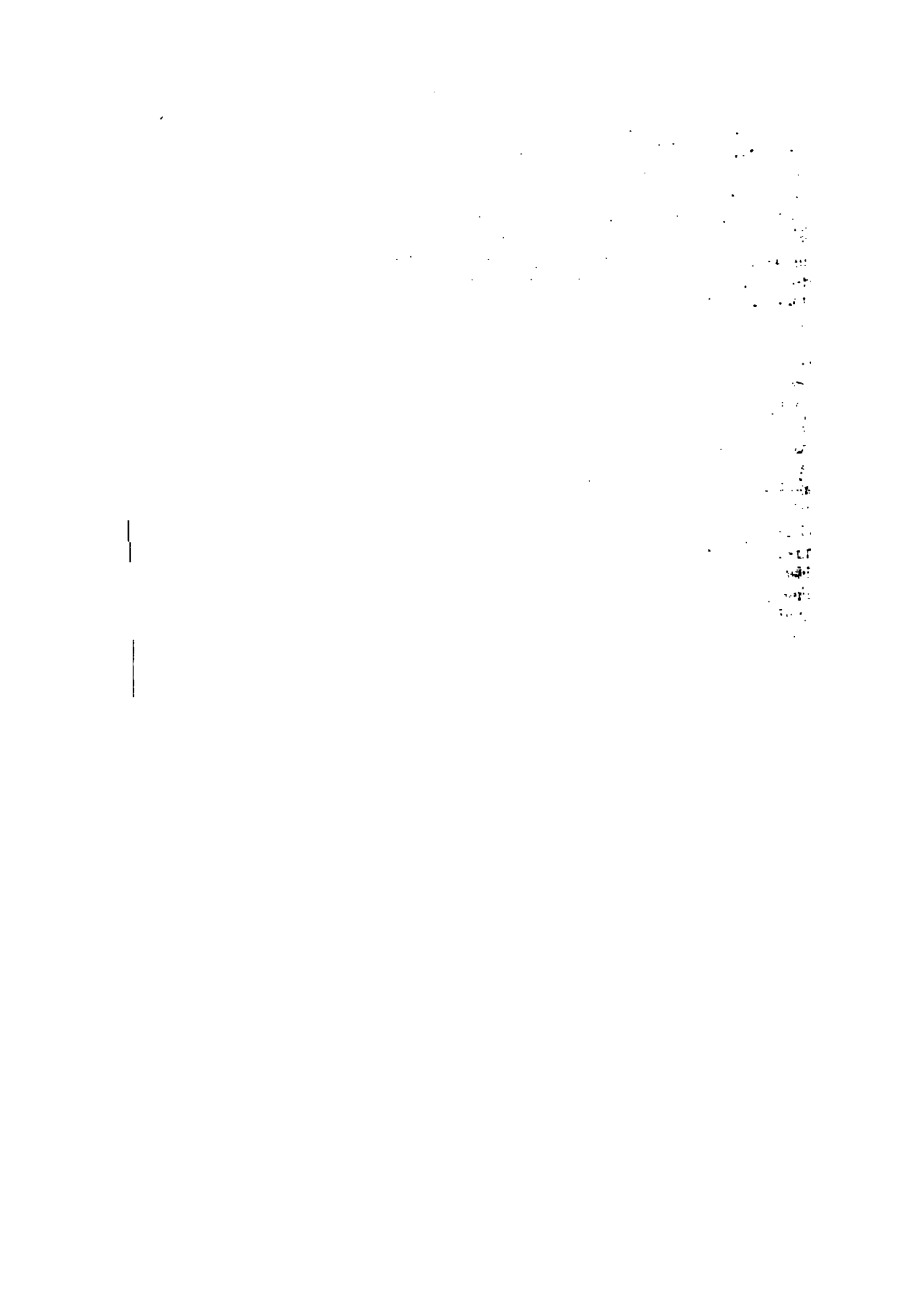
time the proportion of two of sand and one of cement has been adhered to, and there has been no such action.

18 In concrete steel construction generally, it is very certain what will be the condition of the steel used for reinforcing after a number of years; that is, there will certainly be two results only:

19 In constructions where the proper proportion and the proper quality of sand and cement are used, honestly and properly applied, there will be no deterioration of the steel for generations to come.

20 In constructions where ashes, and porous cinders, rubbish, and poor cement are substituted, and indifferently and improperly applied, the steel will deteriorate until the very structure is destroyed in the process of corrosion.

21 In other words, there is no form of construction in engineering requiring more skill and care from the designing to the final erection, and requiring more honest and painstaking watchfulness of details from start to finish, than reinforced concrete construction, and it is certainly a dangerous construction unless in the hands of competent and honest engineers and contractors.



No. 1122

SAW-TOOTH ROOFS FOR FACTORIES

By KNIGHT C. RICHMOND, PROVIDENCE, R. I.
Junior Member of the Society

1 By a saw-tooth, as applied to roofs, we generally mean a form of skylight, a cross-section of which approximates a 30° x 60° draftsman's triangle with the hypothenuse horizontal, the right angle at the top, the glass in the short leg only, and the long leg forming the roof proper. Such saw-teeth can be used singly of any convenient length, in successive rows, or in any desired combination to fit particular conditions. The ridges at the peaks of the saw-teeth may run across the building, or lengthwise of the building, or diagonally, as best suits the requirements of a given case. The object of saw-tooth lights is to obtain overhead light, and in most cases the windows of the saw-teeth are placed facing directly or nearly north, and the angle of the window with the vertical made so small that direct sunlight cannot enter.

2 The saw-tooth form for factory lighting, was first developed, I believe, in England, whence it spread to the continent of Europe, and sometime in the seventies began to be used in the textile mills of the Philadelphia district. Possibly some of the Members can tell of the first application of saw-teeth to factory roofs in this country.

3 At present this form of roof lighting has found wide application in many kinds of factory service. Wherever the space to be lighted is of large floor area, and the occupancy such as to require only comparatively low head room, say from 11 to 20 feet, and where it is desirable to avoid direct sunlight, while still obtaining an abundance of almost perfectly diffused light, there seems to be a use for saw-tooth roofs. Such conditions occur in textile mills, especially in the weaving rooms; in dye houses where light is necessary for the careful matching of shades; in drafting rooms, in many classes of machine shops, and in a great variety of light manufacturing.

Presented at the New York meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions

4 In heavy machine works, where rooms are of height sufficient to accommodate traveling cranes, and buildings are relatively narrow, say not over a hundred or a hundred and twenty-five feet wide, and where a large amount of high light can be provided by side windows, and the direct light from roof skylights glazed with some form of diffusive glass or translucent fabric, there seems to be little use or argument for saw-tooth roofs.

5 The purpose of the saw-tooth form of lighting being, in most cases, to provide direct skylight in large quantity, and at the same time to avoid direct sunlight as far as possible, it follows that north of the tropics the saw-tooth windows must face nearly north, and the angle of the sash with the vertical be made dependent on the latitude of the location, the angle increasing the further north we go. In the latitude of New York, about 41°, this would mean an angle of only 17° to 18°, to keep out the sun in the longest summer days, were it not for the small projecting cornice above the window, and the internal stool or gutter at the bottom. These projections enable us to make the angle of the glass with the vertical greater than we otherwise could do, and with the form of setting and trimming frequently adopted, angles from 25° to 30° have proved satisfactory in practice in New York and New England. The angle of the glass with the vertical could be made much greater, and still keep out direct sunlight, if the cornice above the windows were extended, or a screen or barrier run along the crests of the saw-teeth. A very interesting modification of saw-tooth lighting on the above line has been made by Mr. Willard T. Hatch, a mechanical engineer, in the treatment of foundry roofs, where he has placed the glass skylights on one side only of the successive ridges of the roof, and used the continuous ventilating monitors at the peak of the ridges, as a screen to keep direct sunlight off the glass, thus making the angle of the glass with the vertical much greater than would otherwise be possible, at the same time getting the benefit of the brighter light of the upper sky in much greater degree than would be the case were the same area of glass placed more nearly vertical.

6 Where the angle of the glass with the vertical is made greater than a theoretical consideration of the latitude permits, for the reasons above noted, and the windows face the north, it follows that at seasons when the sun rises and sets north of the equator, that there will be a little direct sunlight on the windows for a little while after 6 a. m., and also for a little while before 6 p. m., solar time being used in the reckoning. Mill hours in the North usually begin about 6.30 a. m. and end about 6.00 to 6.15 p. m., or, in other words, the help work a

greater number of hours after mid-day than they do before it, and where the compass points of the building are not already determined by other considerations, we can avoid in a large measure the direct light of the late afternoon sun in summer by placing the building so that the saw-teeth will face from 5° to 15° east of north, and still not have trouble from direct sunlight before bell-time in the morning.

7 The framing of a saw-tooth roof may be of wood, steel or reënforced concrete, or any suitable combination of the above. No unusual problems are presented other than adapting them to the case in hand, making the obstruction to light as small as practicable. The plane of such roofs is generally nearly level, or only slightly pitched, and the saw-tooth form makes the lodgment of great quantities of snow possible, for which reasons the framing should be of ample stiffness to prevent sagging and the holding of water in puddles on the roof surface. The weight of piping, shafting, motors, machinery, or equipment to be carried, must be considered in each individual case, and provision should be made for the same in the design.

8 In textile mills the roof itself is generally made of matched or splined plank about three inches thick, in accordance with the practice of slow-burning "Mill Construction," and the framing of yellow pine lumber in very simple trussed forms, with members of ample section to meet the slow burning standard. Where steel framing is used, as is common in machine shops, the simplest forms consistent with economy of metal are the best. The writer does not know of a saw-tooth with reënforced concrete framing, but believes it readily adaptable where fire-proof construction is very desirable, as, for instance, in large drafting rooms. Reënforced concrete is reported as successfully used for roofing, and seems to combine great advantages, if lined with proper insulating material to prevent condensation.

9 Any form of roof covering which successfully withstands the attacks of heat, cold, wind, rain, snow, and ice, after it is applied to the steep pitch of the back of the saw-tooth, is available. "Gravel" roofs laid with crushed slag in asphalt, have successfully held on slopes as steep as six inches to the foot in the New England climate, and some of the prepared felted roofings have proved satisfactory. Good materials and extreme care in applying seem to be the secrets of good service on saw-tooth roofs as on others.

10 The usual arrangement of saw-teeth in roofs of large rooms, namely, successive rows of windows, facing north, with the backs of the saw-teeth, which form the roof proper, sloping down to the valley at the bottom of the next row of windows, makes the exposure to old particularly severe, and due allowance must be made for this

in the heating scheme. In textile mills where a relative humidity of 75 to 80, with temperatures about 80° F., is desirable for manufacturing, the tendency to roof and window condensation in cold weather is very large and the usual plank roof is not of itself sufficient to prevent such condensation. Sometimes the planking has been furred and sheathed, dependence being placed on the air space between plank and sheathing to act as a non-conductor of heat, but the writer's experience is that such sheathing is only partially effective, and that condensation is constantly taking place in very cold weather between the plank and sheathing, which works through the joints in the sheathing making drips and stains, and helps to rot both plank and sheathing. Should a layer of good insulating material be placed between plank and sheathing, the result I think would warrant the expense. I have used a double layer of Cabot's sheathing quilt, made of dried sea-weed, between the plank and sheathing of a flat roof of a factory office, with satisfactory results, and at small expense, and the same treatment seems applicable to saw-tooth roofs. Any treatment which increases the insulating power of the roof against the passage of heat, and at the same time does not increase the fire hazard, or cause dirt after it is put in, will increase the comfort of the help in both cold and hot weather, with a lessened expense for heating in cold weather.

11 The portion of the front of the saw-tooth directly below the window stools should be at least as thick and as well insulated as the backs of the saw-teeth, as this part of the roof forms one side of the valley between the lines of saw-teeth, and being out of the line of direct sunlight in the winter, snow will remain there longer than on other parts of the roof, with consequent chilling of the roof.

12 Frequently the sash are double glazed with an air space about three-quarters of an inch between the lights, and this is of undoubted value in keeping heat in the building in cold weather. One glazing is often done with "factory ribbed" glass, the ribs running lengthwise of the window, and the ribbed side placed toward the air space between the lights. The ribbed glass assists in the diffusion of the light, which is sometimes strong, even with a north exposure, due to reflection from clouds. In all cases where delicate shades are to be matched, insistence should be placed on having all the glazing done with white glass to avoid the green tint of the light coming from the ordinary glass, which shows green when looked at edgewise. In spite of double glazing, there will generally be some window condensation which must be taken care of by internal gutters at the bottom of the sash. Such gutters may drain into a system of internal piping,

or have an outlet under the bottom of the sash itself, draining the condensation out onto the roof, the outlet being so arranged that the warmth of the building will keep it open against freezing.

13 The heating of rooms with saw-tooth roofs presents no special difficulties, if the amount of glass and severe exposure are duly considered. Where direct radiation is used, three or four lines of inch and a quarter pipes, heated with steam, or hot water under forced circulation, and placed near the bottom of the fronts of the saw-teeth, and running their entire length, give very satisfactory heating, and prevent in a large degree the troublesome roof and window condensation, by applying heat at the points where it is most needed. If there is no moving machinery in the room to keep the air in motion, wall coils near the floor may also be needed, as for instance in drafting rooms. If the saw-teeth do not extend to the outside walls, and flat places are left in the roof near the walls, direct radiation should be provided for preventing condensation at such places. Some very large rooms, containing about 200,000 square feet of floor surface, have been successfully heated, and very freely ventilated, by drawing air from the basement through steam heated coils, and delivering it at various places in the rooms by means of draft fans and ducts. The chief objection to this method is in the amount of steam necessary for heating, which is undoubtedly greater than for equivalent heating by direct radiation properly applied. Unfortunately I have been unable to get quantitative measurements of the amount of coal needed by the two systems. The fan circulation of air proves its value in hot weather in weaving rooms, according to the reports of those who use it, by affording increased comfort to the help, so that they work with greater efficiency. At such times the fans simply deliver the cooler basement air in large quantity to the working room.

14 The ventilation and cooling in hot weather, of large rooms with saw-tooth roofs, where the height under the framing runs from about eleven to sixteen feet, is a question always needing attention in the design. Such roofs have been built where the sash in the saw-teeth were all fixed sash, and the side walls contained no windows, or only small ones, and ventilation was dependent on small windows in the ends of the saw-teeth, aided by such ventilation as came from a few entrances, and the movement of air through the belt holes in the floor. In hot and muggy weather such rooms became extremely uncomfortable, and some owners have since installed steamboat, or other, ventilators at the ridges of the saw-teeth with satisfactory results. Others have changed some of the fixed sash to pivoted or hinged sash, the chief objection to which is the difficulty of making them tight in driv-

ing storms, on account of their inclined position. In one case noted some of the fixed sash were simply removed, as there was little danger of water damaging the work in the room below. I think the common two-casement window can be readily adapted to saw-tooth skylights by extending the outer casings over the sash rims, and arranging for the upper half only to slide, and by balancing the upper half by spring lifts instead of weights. Revolving "steamboat" ventilators, with dampers in the flues, are easily placed at the ridges of the saw-teeth, and give good service, when made of material which withstands corrosion. The number and size of such ventilators depends entirely on the special conditions in each particular case, and is hardly subject to general rules. Where windows have been placed in the side walls of saw-tooth lighted rooms, it is the writer's experience that these wall windows are generally found open in hot weather, which would seem to justify their existence. As fans are efficient as ventilators in both hot and cold weather, and as direct radiation is more economical for factory heating than indirect acting through a fan circulation, the best service would seem to be given by installing fan capacity sufficient for adequate ventilation only, tempering the air in cold weather, and placing the main reliance for heating on direct radiation.

15 The flashing and draining of saw-tooth roofs has given trouble at times. The great length of flashing in the valleys between the saw-teeth gives opportunity for much expansion and contraction and the piling up of snow in the valleys, with a relatively warm roof melting it on the underside, gives a chance for water to work up over the lower flashing, unless the same is of ample height and very carefully put in, and provision made for promptly carrying off the water from the melting snow. Where the saw-teeth run across the building, the roof is often pitched from the center ridge to both sides on a slope of a quarter to a half an inch per foot, and the water carried off in conductors which run down on the inside or the outside of the outside walls. Outside conductors have proved very undesirable in New England on account of the water freezing as soon as it has passed from the warm surface of the roof to the cold outside conductor. The result is a great mass of ice, and generally a broken conductor. It is altogether desirable, in climates where water freezes in the winter, to run the conductors down on the inner face of the side walls and to make both the strainers and conductors of ample capacity to carry off any probable amount of rain or melted snow.

16 Where the ridges of the saw-teeth run with the length of the building, water can be most conveniently removed from the valleys

by conductors placed at intervals of 40 to 60 feet apart in the valleys. Experience in New England seems to show that a three inch conductor so placed is amply sufficient to take care of 1000 to 1200 square feet of roof surface, providing the conductor has a free downward run of 12 or 15 feet. A slight pitch of the bottom of the valley toward the conductor opening in the roof, is easily effected by furring up the roof under the roof covering. In a roof recently built from the writer's design, a pitch of three inches in 20 feet proved amply sufficient to remove all the water from the bottoms of the valleys. The conductors after coming through the roof can be connected into a larger pipe near the roof, or be carried down through the room, and be disposed of in the basement. The strainer on the roof often fits into a roof thimble made tight with the roof covering, and the thimble runs down into the conductor pipe proper. The connection of the roof thimble with the top of the conductor is frequently a slip joint, made by slipping the thimble some twelve inches down into the conductor, and when the pipe connecting the conductors is near the ceiling, and only slightly pitched, there is danger, in very heavy rains, of its filling, and of the water backing up and overflowing between the roof thimble and the top of the conductor, unless the connecting pipe is made of very ample proportions. I think it is better to carry the conductors down to and through the floor and gain the effect of the head in the vertical pipe to rapidly discharge the water. The conductors themselves should be of stout construction, where they come down through the room, and ordinary wrought iron pipe has been found a satisfactory material. Cast iron soil pipe is liable to be broken, and the sheet metal conductors of commerce are sure to be bent and dented in factory service. When columns are of iron pipe, or of hollow cast iron, they can be readily utilized for roof conductors, and where the columns are not used for conductors, the conductors can be run in line with the columns without wasting valuable floor space. The writer's feeling is that it would generally be better to make the plane of the roof level, even when the saw-teeth run across the building. This brings the girders carrying the saw-teeth all on a level, and the room is of uniform height under the girders, which in some measure simplifies the installation of machinery and shafting. Where there is no overhead shafting, a difference of a few feet of the height of the roof at different points may make no difference in the value of the room as working space, and it is cheaper to drain the roof by a few large conductors at the ends of the valleys at the outside walls, than by a system of small conductors at intervals, as described.

17 Even with the amount of light furnished by a properly proportioned saw-tooth roof, a very large gain is made by a thorough whitening of all interior surfaces, and this should never be omitted where light is of value, and where there is any probability of the paint remaining white after it is applied.

18 The fire hazard of saw-tooth construction presents no difficulties from the insurance point of view, as far as I can ascertain, and no discrimination in rates is made against such construction. While the serrated form in some measure prevents the free play of hose streams against the ceiling, the same form also tends to prevent the free advance of fire in a direction across the ridges of the saw-teeth, and the great number of roof windows make it possible to attack the fire at any point by hose streams from above. The very large area of many rooms with saw-tooth roofs, rooms with 100,000 to 200,000 or more square feet of floor without partitions offer the objections, from the insurance point of view, made to all such large spaces, but the installation of automatic sprinklers with ample water supply, in accordance with the insurance regulations, overcomes such objections as far as they affect rates. In other words, the large saw-tooth lighted room is insured at the same rate as the remainder of the factory, providing the occupancy is the same. At this point it may be noted, that while the simplest forms of framing with a few very substantial members are always desirable when building in accordance with the slow burning requirements of "Mill Construction," nevertheless the growing use and ready adaptability of structural steel framing, and the rising price of lumber, with the difficulty of obtaining large sizes promptly, which almost compels the substitution of trussed forms and smaller sticks, makes the consideration of such forms almost a necessity, and I do not find that they are prejudicial to insurance rates, providing always the sizes are kept reasonably large, say not less than 6″ x 8″ in members under compression or acting as beams, and providing also that there are sufficient sprinklers and water to reach all parts of the framing exposed to fire. While a few years ago, yellow pine was much cheaper than structural steel, strength for strength, today the difference in cost is so small between sizes of yellow pine of say 10″ x 16″ and up, and a steel beam of equal strength, that it is sometimes economical to use steel in place of lumber, and saw-tooth roofs are successfully built with a combination of both materials in the framing.

19 The amount and diffusion of light can be made almost perfect for the most exacting requirements, and this is the preëminent advan-

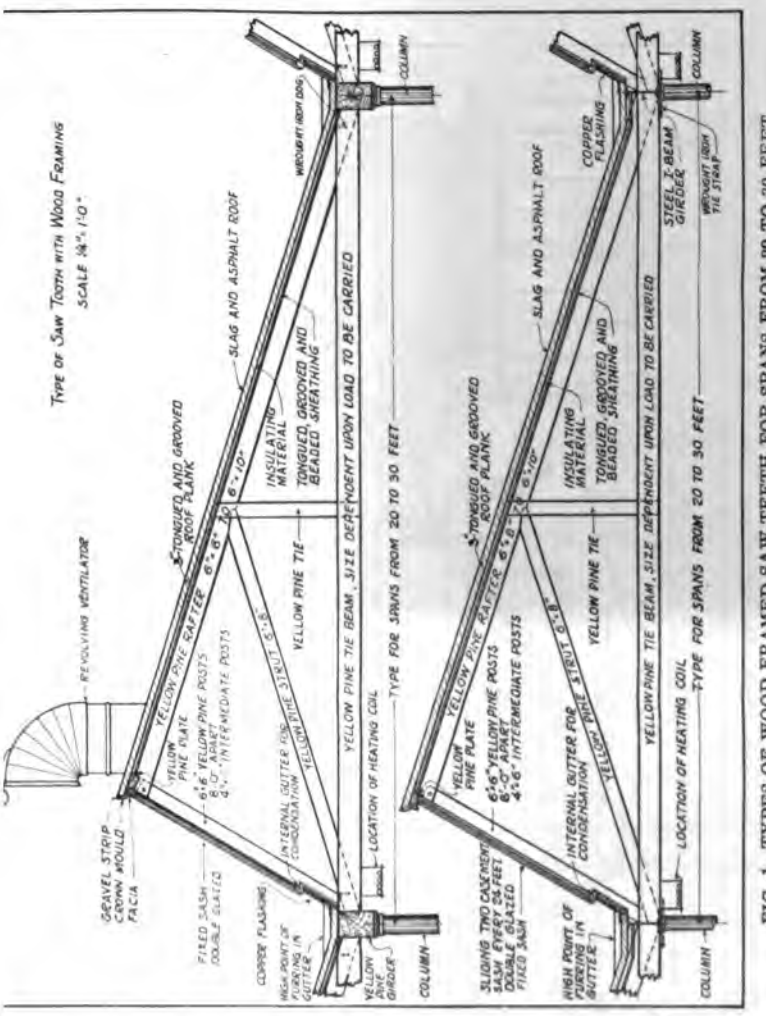


FIG. 1 TYPES OF WOOD FRAMED SAW-TEETH FOR SPANS FROM 20 TO 30 FEET

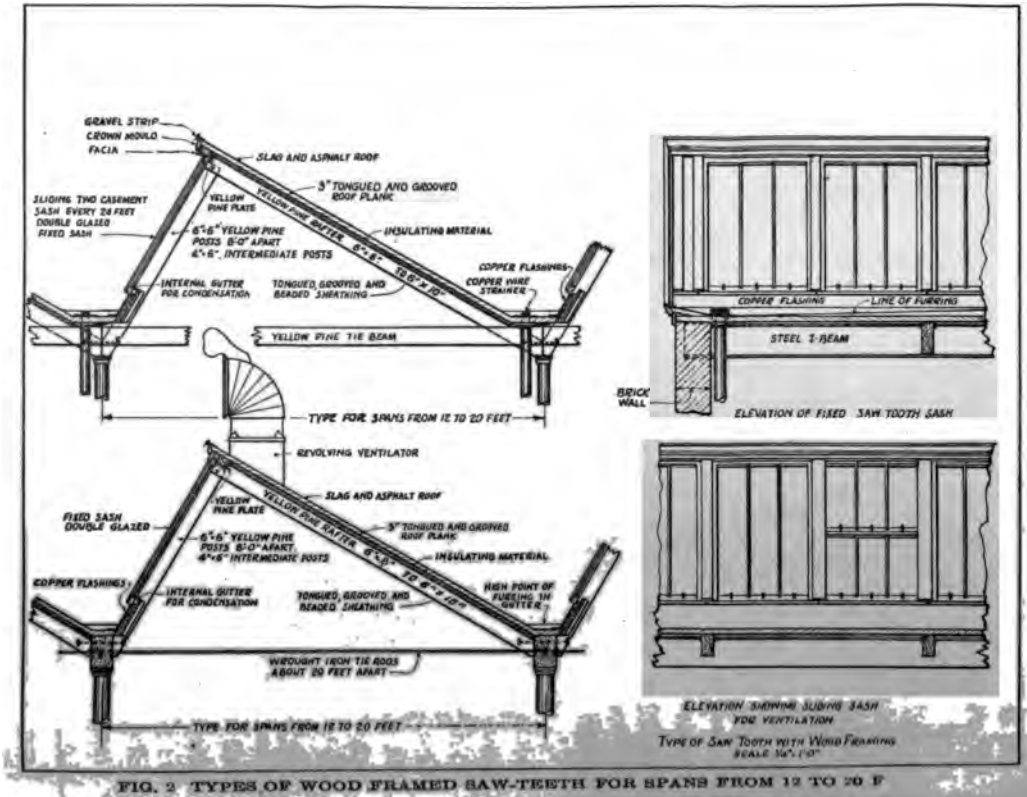


FIG. 2 TYPES OF WOOD FRAMED SAW-TEETH FOR SPANS FROM 12 TO 20 F

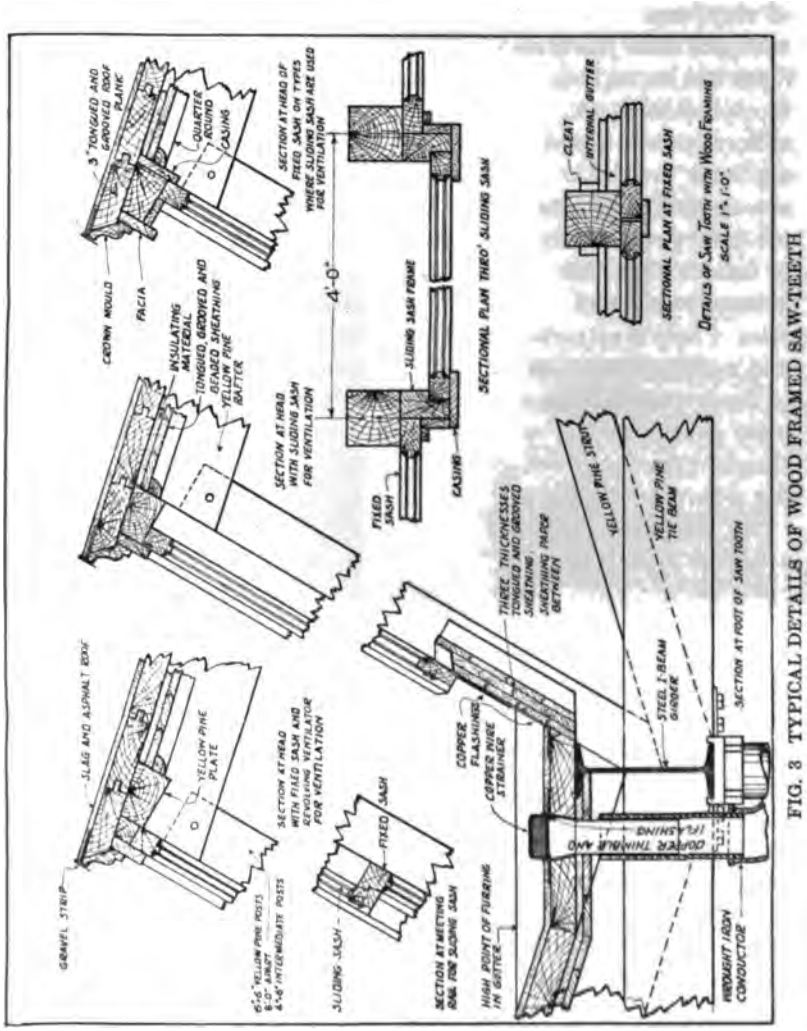


FIG. 3 TYPICAL DETAILS OF WOOD FRAMED SAW-TEETH

tage of saw-tooth lighting. By no means a small economy in the use of saw-tooth roofs is the saving in time during which artificial light is needed, as compared with side-lighted rooms in factories of usual proportions. One textile mill in which a saw-tooth lighted building of very large area is near a several storied building about ninety feet wide, the same processes being followed in both buildings, reports that lights are on an hour earlier in the storied building than in the saw-tooth building. As the lighting frequently runs up into the hundreds of horse-power, the saving is material. It is frequently reported that a greater production of the same class of goods is obtained from saw-tooth lighted rooms, than from side-lighted rooms, with identical machinery running at the same speed in each, and it is somewhat hard to believe that the difference exists. The explanation seems to be primarily in the almost perfect light, and from the fact that a better class of help is attracted and retained for the very reason that the light and working conditions are better. In one case at least the advantage of the saw-tooth lighted building is distinctly measured by the lower piece price paid for weavers in the saw-tooth building as against the piece price paid weavers on the same class of work in the neighboring side-lighted building. The difference is stated to be ten per cent.

20 The cost is undoubtedly greater for a saw-tooth roof, than for a flat or other plane roof. The actual amount of roof is almost as great ordinarily in the saw-tooth form as in the plane form, and may be more, and in addition there is more framing, all the windows with their trimming, all the flashing below the windows and in the internal gutters, a large amount of painting, frequently a larger cost for conducting water from the roof, and a larger cost for the heating and sprinkling, as compared with plane roofs. These items may increase the cost of a saw-tooth roof from 40 per cent to 60 per cent over a plane flat roof without skylights, but this can hardly be considered a fair measure, as to obtain results fairly comparable with properly designed saw-tooth lighting, the engineer must consider the whole cost of side lighted buildings of sufficient height in the stories and sufficiently limited in width to give satisfactory light, and should also consider the whole cost of the saw-tooth lighted building. Where the work or process requires large amounts of nearly perfect light, or where the work is bettered or done at less cost by having it, the final balance of advantage seems to incline strongly toward the saw-tooth form, as is evidenced by the great increase in recent years in the use of saw-tooth lighted buildings. This is very noticeable in buildings erected for fine and fancy weaving. Many of these have been designed by Members of the Society who make a spec-

ialty of textile mills, and who early recognized the advantages of this type, and now such buildings may almost be considered as the standard form for this class of work, with the saw-tooth trusses made in the simplest forms.

21 The proper proportioning of the saw-tooth light is important to obtain the best results without wasting money in their erection. Some saw-tooth roofs have been designed with the span of the saw-tooth very short relative to the height, thus making the backs of the saw-teeth very steep, and the valleys sharp and narrow. The result seems to be some loss of light, on account of the obstruction formed by the backs of the saw-teeth themselves, and there is an unnecessary expense for glass and flashings, as fewer saw-teeth with longer spans or the same number of saw-teeth with shorter windows would give all the light needed. The photograph below shows a roof

FIG. 4 NEW ENGLAND WEAVING MILL. SAW-TEETH CRITICISED AS TOO HIGH FOR THE SPAN

against which this criticism is made. The experience of the writer after an examination of the lighting effect in a very considerable number of saw-tooth lighted rooms, designed by different engineers, is that to obtain the best results, there should be no intervals between the saw-teeth. A flat place on the roof generally means a shadow, even if slight, or perhaps only a less brightly lighted area, and makes a break in the otherwise almost perfect diffusion of the light. By the same reasoning the obstruction caused by the necessary space and flashings below the windows and by the supporting girders carrying the saw-tooth frames should be kept at a minimum. With attention paid to these points, a proportion of height of window to length of span of the saw-tooth, in the ratio of 1 to 3½, or 4, gives all

the light desirable in this climate, and if this ratio is exceeded I think it is at the expense of greater first cost for glass, and a greater running cost for heating, although special conditions may make the proportions given unsuited to a given case. The following photograph of a factory which the writer noted in Mexico is interesting in the fact that the fronts of the saw-teeth have a large part of the surface boarded up, and only a few sash are placed where we generally try to get all the light we can. This particular factory faced fairly to the south, and it is also interesting to note that direct sunlight was particularly undesirable in the processes carried on inside.

22 The three drawings shown in Figs. 1, 2 and 3 show types of saw-teeth framed in wood, with some details, which the writer believes meet

FIG. 5 RUBBER FACTORY IN NORTHERN MEXICO (FACING SOUTH)

the requirements of this latitude. Very little originality is claimed for these, as they are the result of experience gained in the examination of many different roofs designed by many different men, combined with the statements of those who have used the roofs and the experience of the writer's personal practice in trying to overcome some of the troubles which have been noticed or reported. Many of the members can doubtless suggest forms and details which they have used, and which meet conditions better than anything noted, and it is from these that the writer hopes to hear.

23 In closing I wish to acknowledge the courtesy uniformly shown me in gathering data for the paper, and to express my appreciation of the help rendered by my assistant, Mr. E. E. Hobbs, in preparing the drawings.

DISCUSSION

MR. SAMUEL M. GREEN In my discussion of Mr. Hind's paper on this same subject I have given my experience and views on most of the points raised by Mr. Richmond. I wish to emphasize one or two of them however.

2 The consideration of the angle of glass, as related to the direct rays of the sun, is not nearly as important as Mr. Richmond's paper would lead one to think. Great care to secure the correct theoretical angle would be spoiled, in most cases, by the simple fact that absolute north exposure is seldom obtained, and as I have mentioned in the discussion of Mr. Hind's paper, the slight amount and duration of direct sunlight obtained by an approximate north exposure and by about a 60 degree angle of glass, becomes entirely unnoticeable when factory ribbed glass is used.

3 Proper proportioned forced ventilation will obviate the necessity of carrying a high degree of humidity in textile work and therefore reduces considerably the extreme condensation effects, particularly the necessity of using a heat insulating material on the roof other than 3 inch matched planking.

Mr. L. H. KUNHARDT I will comment on a few of the points in Mr. Richmond's paper. My remarks regarding this type made in connection with Mr. Hind's paper might, however, follow either paper.

As regards paragraph 4, it is my belief that the saw-tooth type is also adapted to the heavy machine shops he mentions, especially so in shops having galleries on either side of the high center section over the cranes. This center section can be made of the saw-tooth type and the result is most gratifying, for without it there is apt to be a relatively dark space directly under the center and along the columns carrying the cranes.

2 Referring to paragraph 10, plank roofs without hollows are to be preferred, under practically all conditions, to those with hollow spaces. The light inflammable sheathing with spaces behind it is readily combustible and such condensation as may occur inside the space rots roof plank and the sheathing. If 3 inch roof planking is sufficient for flat roofs why not also for the saw-tooth form? Good circulation of air ought to prevent all possibility even of trouble, which, however, I do not believe is likely, except in wet rooms where condensation is bound to occur whether the room is under a roof or a floor of the story above.

3 Referring to paragraph 16, I would advise against furring up the roof under the covering. This provides the objectionable hollows again, and in even a worse place, under the valleys where leakage, if it occurs, will cause rotting. I would advise inserts on top of the timbers cut of varying heights, so that the roof plank when spiked to them may take the slope desired for the valleys. It is necessary, as stated in the paper, however, that the girders be all on a level, so that the room may be of uniform height under them, but it makes no difference if the planks of the roof are of varying height to provide slope for the valleys.

4 In paragraph 18, the mention of areas brings me to add one caution—that they should not be too large. Subdivision of a property is desirable, not only from an insurance point of view, but also from that of the owner. Does he himself wish to face the possibility of a single fire wrecking his entire plant, as has happened in many cases, and in which, also, had it been of two or three times as large area, all would have gone down in the destruction. Areas need to be of proper size for economical shop management, but there is a limit beyond which there is no gain, and perhaps, on the contrary, a distinct disadvantage. Yard space is fully as valuable as buildings, under some conditions, and there comes a time, even though sprinklers, as stated, overcome objections so far as rates are concerned, when insurance companies have to reduce their lines on account of the congested values in one area or fire risk.

5 I brought up this point at one of the large risks insured by us, the Allis-Chalmers Company, West Allis Works, where they have an excellently designed plant for handling their material. They have several wings extending from a large erecting shop and parallel to each other 70 feet apart, over which spaces are cranes for handling heavy castings in the yard. I brought up the question of area with them, as it had been suggested that these spaces be roofed over, and succeeded in preventing this, showing them the advantages of yard room as well as area inside of buildings. The gain was not only from an insurance standpoint, but from that of the owners, as they now do not risk so large a manufacturing plant all in one area, subject to a single fire.

MR. H. V. HAIGHT I wish to comment on Mr. Richmond's paper simply to draw attention to some advantages in making the saw-teeth with window faces vertical. We are using this style on a foundry 100 feet wide which has a central bay 50 feet wide and two side bays 25 feet wide. Wishing to have particularly good light in the centre

bay, we have made the roof of this part on the saw-tooth style, but with vertical window faces. We made these faces vertical for two reasons, the first being that it permits the use of ordinary windows instead of the expensive skylights. The other reason was that we wished to provide for double windows, as is usual in this climate. The question of double windows had considerable weight with us, as they make a reduction in the size of the plant required to heat the building, and, of course, in the running expenses of heating also. The windows in the saw-teeth being the highest ones in the building, are the ones which it is most necessary should have double sashes. When we were considering the inclined window faces we referred the double window question to several manufacturers of skylights, but none of them offered any solution.

2 Another form of construction which was offered to us consisted of cross monitors on top of the main bay, these monitors having windows all round. It appeared to us that this construction would hardly give as good lighting as the vertical face saw-teeth, as the saw-tooth construction seems to be better suited to reflecting the light from the roof through the windows and from the ceiling down to the floor.

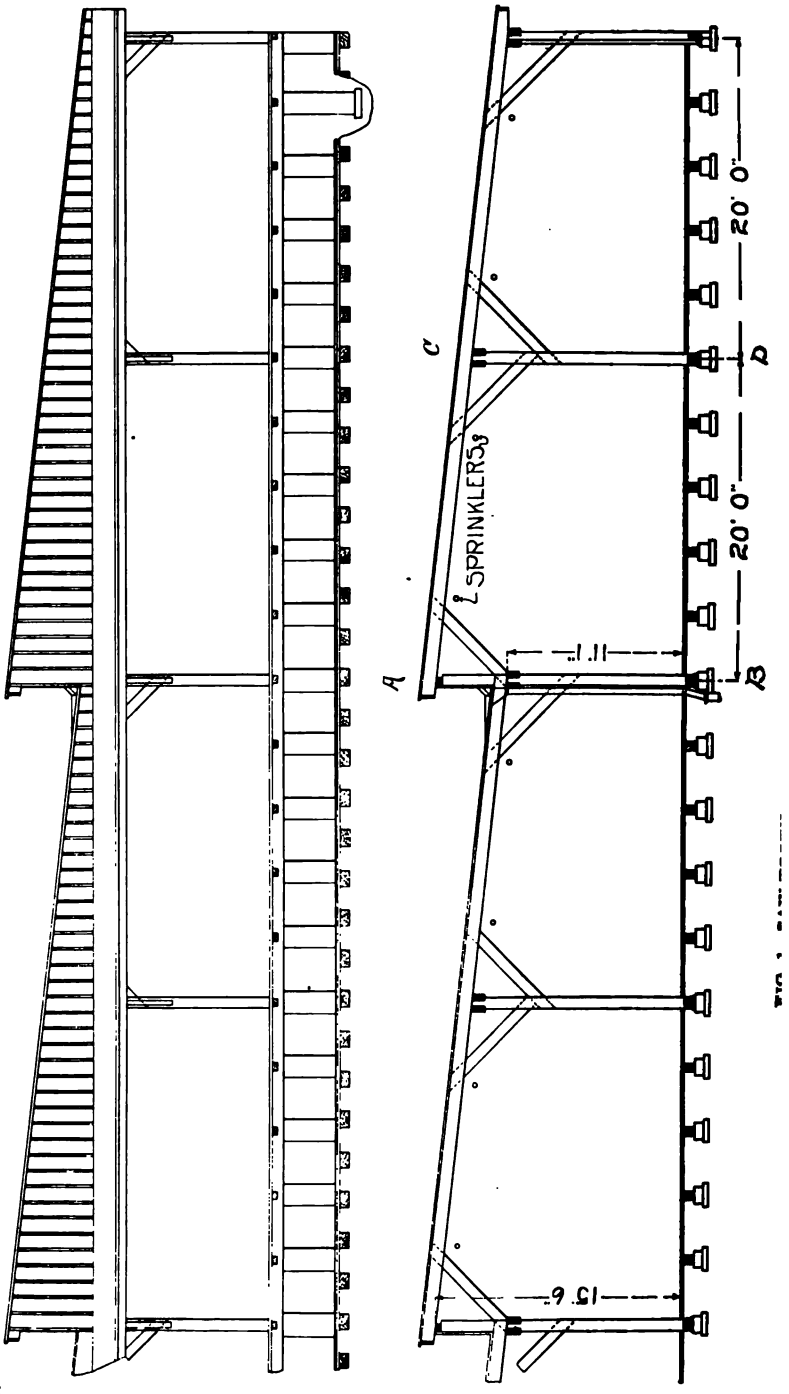
3 The vertical face saw-tooth also adapts itself well to the steel construction, as instead of resting the whole saw-tooth construction on carrying-girders, the vertical face of the saw-tooth is made a light truss, which takes the place of the girder.

4 The window sills of the saw-teeth windows are about 14 feet above the highest point of the valley to obviate any trouble from snow. The building has interior drainage throughout, as we have had considerable trouble with the exterior drainage of the old shops, due to ice on the jets.

5 When the saw-tooth construction is used for machine shops or foundries, it does not appear essential to face the saw-teeth north. The most common construction for such shops is the monitor style, and there seems little objection in that case to light from the east, west, or south. Some go so far in the endeavor to face the saw-teeth windows of a machine shop due north as to run the teeth lengthwise or even diagonally of the shop, which appears absurd. We are facing the saw-teeth east.

MR. J. R. FORDYCE The preliminary state of cotton manufacture, so long in a primitive state as compared to the final or mill end, has at last started on an awakening.

2 The saw-tooth roof, which as a means of lighting weave sheds


C
SPRINKLERS
A
B
D
20' 0"
20' 0"
15' 6"

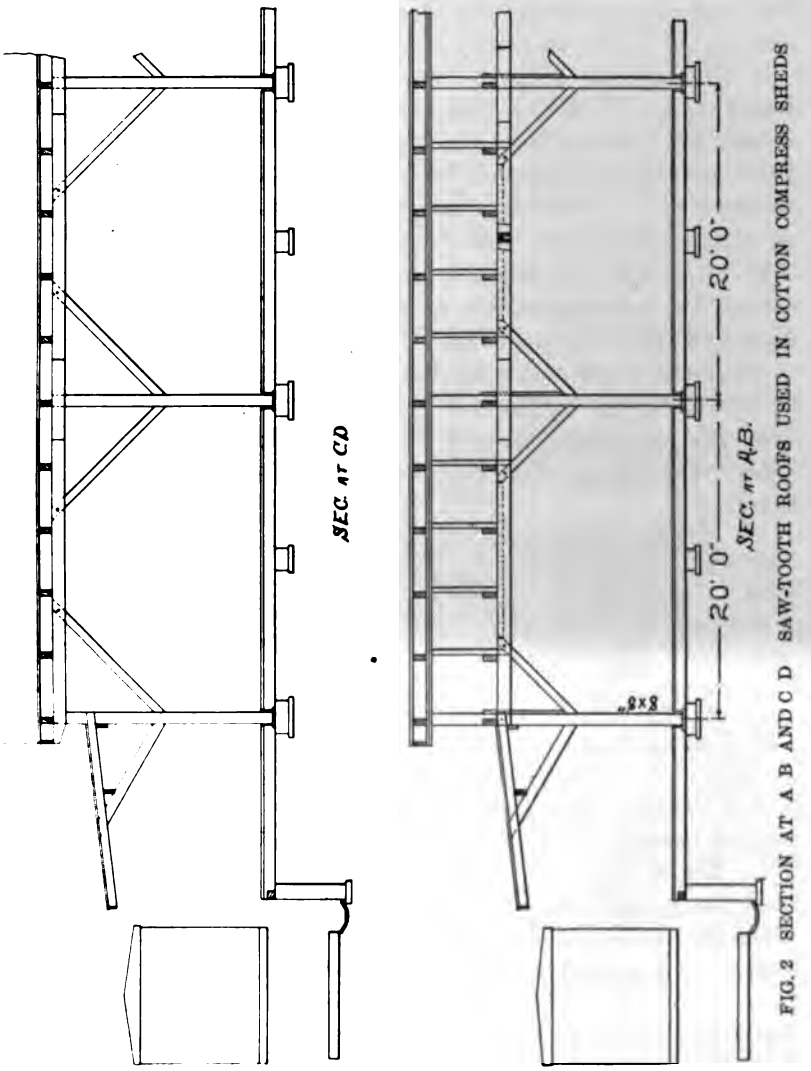


FIG. 2 SECTION AT A B AND C D SAW-TOOTH ROOFS USED IN COTTON COMPRESS SHEDS

has long been in use, is now applied to cotton compress sheds. Owing to the great bulk of the cotton bales and the fact that the crop is nearly all rushed into the compresses during October and November, the sheds are necessarily very large, and as they are unused during a long period of the year, they have to be cheaply constructed.

3 The bales are brought into the sheds from the country gins on wagons and cars, and are then weighed, sampled, and marked. This takes a great deal of room and a good light is needed. As an enormous number of bales must be handled in so short a time, it is not economical to pile the bales on one another. Therefore, the sheds do not have to be very high.

4 To reduce the insurance rate on such large accumulations of cotton, automatic sprinklers are installed, and to be effective they must hang just over the bales. To meet all of these conditions, the sheds shown in the accompanying drawings have been designed and erected at various cotton centers in the South.

5 The construction is light, because we do not have heavy snow loads. The spacing of the posts are governed by the following conditions:

a Sizes of the cotton bales, which are grouped in lots of one hundred for sorting purposes;
b the available sizes of timber for rafter girders, etc.;
c the spacing of the rafters required by the spacing of the automatic sprinkler heads;
d the dead and live loads the roof has to carry.

6 The opening in the roof is vertical instead of inclining, on account of being simpler and cheaper in construction. The width of the opening is determined by the amount of light required and the pitch of the roof, which is covered preferably with tarred and graveled felt. The openings are turned south, instead of north, because we want the sunlight to dry out the cotton and warm up the negroes. When the roof is pitched toward the north it lasts longer in our climate than when it is pitched toward the south, owing to less direct rays of the sun, and, therefore, less evaporating effect on the oils in the felt. The sun also shines directly into the gutter and prevents the accumulation of ice and snow. The openings are covered with "wire fabric" to prevent the entrance of sparks, wind, and water, and because it is cheaper than glass.

7 The gutters are formed by wedges under the sheathing, giving a cross pitch of $\frac{1}{4}$ of an inch to the foot. No metal is used, but the felt is of double thickness along the gutter.

8 The conductor heads are spaced 40 feet apart, the down spouts, four inches in diameter, follow down the posts, and lead into tile drain pipes under the floor. These sheds seem to meet all of the conditions, and are satisfactory to all interests concerned.

MR. FRED S. HINDS Paragraph 4 would imply that Mr. Richmond considers there is little use of argument for saw-tooth roofs on heavy machine shops or buildings which are relatively narrow, for instance, not over 100 to 125 feet wide. This I would consider fairly wide shops, and if more space could have been allotted for my photographs, I would have shown the DeLaval plant which has the saw-tooth skylights in the side isles or galleries, or on both sides of the crane shop. This method of lighting the side isles or galleries is very desirable to keep down an excessive height of the side walls required for side windows.

2 As machine shops are costing about 20 per cent more today than a few years ago, the height of buildings can be reduced at least 20 per cent by the introduction of saw-tooth skylights, thus bringing the cost of a new plant down to normal conditions.

3 Again, on referring to Paragraph 19, this paper reads: "....almost perfect for the most exacting requirements, and this is the pre-eminent advantage of saw-tooth lighting. By no means a small economy in the use of saw-tooth roofs is the saving in time during which artificial light is needed, as compared with side-lighted rooms in factories of usual proportions.....The explanation seems to be primarily in the almost perfect light, and from the fact that a better class of help is attracted and retained for the very reason that the light and working conditions are better. In one case at least the advantage of the saw-tooth lighted building is distinctly measured by the lower piece price paid for weavers in the saw-tooth building as against the piece price paid weavers on the same class of work in the neighboring side-lighted building. The difference is stated to be 10 per cent."

4 In revising the paper, would it not be well for the author to hold to paragraph 19 and eliminate paragraph 4?

5 In paragraph 5, Mr. Richmond makes a strong point in favor of a greater angle than that called for in my paper, and due credit should be given him for bringing out this feature, which is further illustrated by diagram, Fig. 1, herewith.

6 The secret of it is not the small projecting cornice, as I have considered it, and as will be noted in my paper, Fig. 3, but a stronger projection, as brought out in Mr. Richmond's paper, Fig. 3, which

increases the angle from 19 to 30 degrees from the vertical. However, in all the other types, discussed by both papers on this subject, there is no instance where anyone has used this strong overhanging projection, or cornice, but they have used the 30 degree, and this surely admits rays of sunlight.

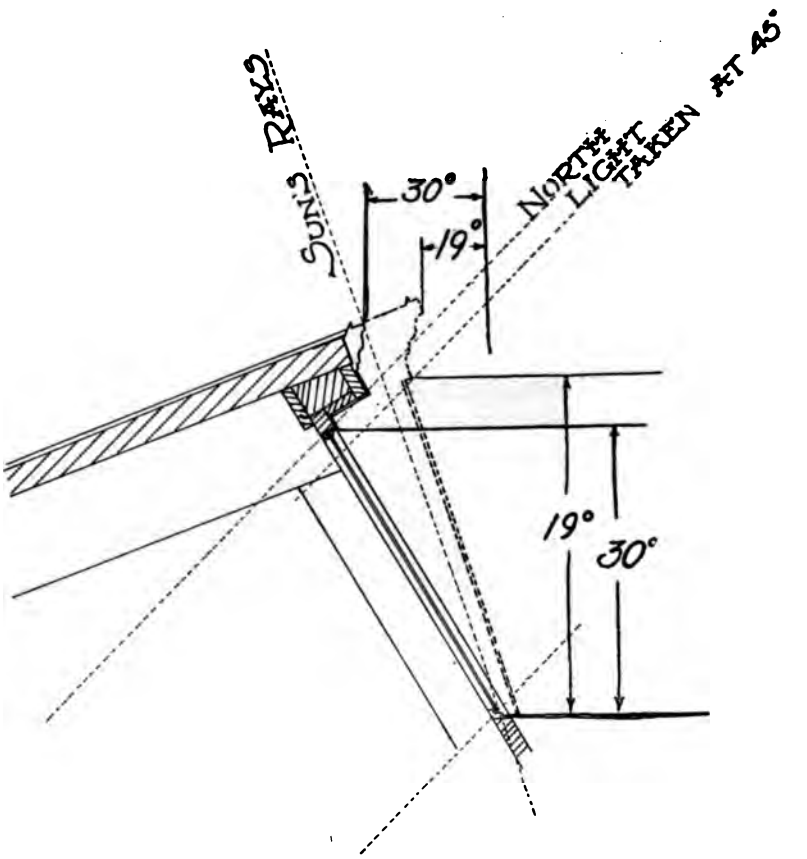


FIG. 1 DIAGRAM ILLUSTRATING APPLICATION OF OVERHANGING CORNICE

7 Therefore, the model for saw-tooth skylights is very easily compared by the other reference made in Mr. Richmond's paragraph, which describes it as a draftsman's 30 x 60 degree triangle, with the hypotenuse placed horizontal.

8 Paragraph 6 should be particularly noted for the reason that quite often in the designing of new factory plants, it is impossible to have the saw-tooth skylights face north and run either across or lengthwise of the building, to conform to the lines of the property.

Thus there is an advantage in the 5 to 15 degrees which the buildings can face east of north and at the same time avoid direct sunlight before the whistle in the morning.

9 I would still further enlarge upon paragraph 9 and say that I consider gravel roofs, or prepared gravel roofs, not so well adapted to the long slant or back of skylights on account of the steep slopes, as the crushed slag in asphalt mentioned in this paragraph.

10 Paragraph 10 may have been Mr. Richmond's experience in mill work rather than that of factories or machine shops, for the reason that he makes a strong point that even 3 inch hard pine plank must be properly insulated to avoid condensation.

11 In my work of 27 years in planning industrial plants and textile mills, one of my first experiences was the use of 2½ inch plank on the roof of one of the three mills erected for the Washington Mills Plant and on the Plymouth Cordage Company's one-story plant.

12 Condensation was discovered and the cause was finally laid to insufficient thickness of roof plank. At this time I began to use 3 inch plank which has eliminated the difficulty. As far as I know, on all the plants where I have used this thickness of plank there has been no further trouble.

13 I cannot see how there would be any trouble with double-glazed skylights in any of our factories or machine shops, unless they were over departments where the temperature would be about 80 degrees F. and a humidity of 70 to 80 degrees. From this it will be seen that the only place where insulation is required, if at all, is in textile plants.

14 As Mr. Richmond has reference more particularly to textile mills, it may be that there was insufficient or no ventilation provided.

15 Paragraph 15. In reading this and examining the various types of saw-teeth in Figs. 1, 2, and 3, it is very evident that they are all of the English type. On a large part of these cuts he refers to the gutter between the skylights. Here is the weakest point in all these various designs of saw-tooth skylights, where, I contend, in preference to a gutter of any form, whether of sheet metal or cast iron, the flat roof space is the most practical.

16 I do not approve of the method of carrying off roof water by conductors in valleys or flat spaces between saw-tooth skylights, and avoid it in every way possible. The method of sloping the roof toward the walls in order to carry away the water as quickly as possible from the back of these skylights is the surest method to avoid the troubles from water and snow collecting and freezing around the conductor outlets.

17 With saw-tooth skylights running lengthwise of the building, it is impossible to carry out this idea; therefore, there is all the more reason for having a wide space at the bottom of the saw-tooth, or what I designate as my Americanized system; namely, the flat roof space between each skylight, of 24 to 48 inches in width, according to the circumstances. This variation being in the slant of the back which is controlled by the height of the glass, should never be less than 24 inches wide.

18 Referring to the cost of saw-tooth skylights over that of the flat or plain roof, under paragraph 20, and in answer to the statement that this type of skylight increases the cost over the plain roof from 40 to 60 per cent, I would state that the increased advantage of a saw-tooth skylight is in bringing it down nearer to the work than would be possible with the usual high stories, and this I accomplish by reducing the height of the stories about three feet, thus saving three feet of brickwork over the whole area of the building and slightly saving the stock in the length of the columns. I believe this saving pays for the additional cost of my plain design of saw-tooth skylight.

19 I cannot agree with Mr. Richmond to bring in the increased cost of heating and sprinklers, for the reason that the great advantage of saw-tooth skylights should entirely eliminate these two items. In fact, when we consider that the saw-tooth form is simply raising one end of the roofing and setting that part of it on an angle, to admit of the space for the sash, and that it requires no more roofing space than it did when it was down on the level, how does it add a great many sprinkler heads?

20 Accompanying this discussion I wish to introduce a diagram, Fig. 1. The dotted lines of the skylight show the sash at an angle of 19 degrees, the lines in full of the skylights show it as 30 degrees; but with the addition of the overhanging cornice, with just enough projection to eliminate all direct rays of the sun.

21 On the basis of 48 inches of height of glass on which this diagram is laid out, there is a gain of 7 inches in width of light from the zenith and 3 inches more of north light, when based at an angle of 45 degrees, for the reason that the 48 inches of glass is tipped down nearer to a right angle with the angle of north light, making a gain of 3 inches more, thus securing practically 10 inches of stronger light.

22 It is only possible to throw light through a space of 48 inches but if it can be increased by 10 inches with a stronger light, gaining the advantage of the zenith light, there is no question but that this is an improved method over any other type.

THE AUTHOR I was much interested in Professor Sweet's discussion of Mr. Hinds' paper, as a saw-tooth roof of similar detail to that described by Professor Sweet has been in use for some years at the Port Chester Bolt and Nut Company and was found so satisfactory that the design was copied in extending their machine shop, about seven years ago.

2 Referring to Mr. Green's statement that properly proportioned forced ventilation will obviate the necessity for a high humidity in textile work, and therefore some of the troublesome roof condensation, I think it fair to state that the most serious cases of roof condensation which I have seen have occurred in two weave sheds where a fan system of heating was used. In each case the air was drawn from the basements which were, I confess, somewhat damp, and forced through heating coils and delivered by ducts at various places in the weaving floor. There was no means of regulating the humidity of the basement air, but the roof condensation was in evidence to an unfortunate degree.

3 Mr. Kunhardt misunderstood my meaning when he thought that in furring up the roof, I countenanced leaving any hollow spaces. My use of the word *furring* was perhaps misleading, for I have always used solid filling under the roof covering without concealed air spaces.

4 In spite of Mr. Haight's reasons, I still feel that the greatest efficiency combined with economy is reached by inclining the sash as far as possible from the vertical without introducing troubles from direct sunlight.

5 Mr. Fordyce's interesting saw-tooth roofs meet his conditions well, but our troubles are quite as much in keeping cool in the summer, as warm in winter.

6 I am indebted to Mr. Hinds for his criticism of my statement that there is little argument for saw-tooth roofs in heavy machine shop work. The discussion has shown their advantages in many places in such work, especially when great height is not necessary, and I gladly accept the amendment. My feeling is still in favor of conductors passing down inside the building, rather than pitching the roof for draining the water to the walls. Some bad cases of frozen outside conductors, and damage to roofs from ice forming at the jet, have made me feel that it is more satisfactory, in New England at least, to keep the roof water away from the outside walls.

7 The discussion has brought out so many interesting and valuable points, that I hope it may be continued, and that the perfect saw tooth roof may shortly be evolved from the varied experiences of the different members.

No. 1123

A PLAN TO PROVIDE FOR A SUPPLY OF SKILLED WORKMEN

By MAGNUS W. ALEXANDER, LYNN, MASS.
Member of the Society

1 Seven years ago, at the annual meeting of this Society, Mr. Milton P. Higgins, of Worcester, Mass., analyzing the industrial situation of that time, pointed out the significance of the lack of competent mechanics. He sounded the note of warning that unless the educational system should provide as efficiently for the training of the future skilled mechanic as it now provides for the training of those who will ultimately become leaders in industrial occupations—engineers, superintendents, and managers—there would arise a serious handicap to the development of American industries. The paper aroused much interest and provoked a helpful discussion, and the ideas set forth were echoed in the technical press and reiterated in educational circles.

2 American industries, in the meantime, have developed at a tremendous pace, and their character has undergone significant changes. Specialization has become the American watchword and the spirit of it has permeated all branches of industrial activity. While specialization in manufacture on a large scale, naturally tends to lessen the demand for all-round skilled artisans, yet on the other hand, the enormous expansion of modern industries requires a greater aggregate of skilled mechanics today than it did a decade ago; and, moreover, the degree of skill needed on account of the specializing processes and the highly complicated specializing machinery has been materially advanced.

3 Are we sufficiently supplied with mechanics who answer these present-day demands? Evidently not; otherwise the industrial training of the masses for positions at the bench and at the machine would not be such a burning question as it is today. The great amount of

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discussion and printed matter on the subject, the organization of committees for the study of the problems, and the appointment of State commissions, such as the Massachusetts Commission on Industrial and Technical Education, all illustrate the vital interest of the people in this question.

4 The admonition of Mr. Higgins, it seems, has not produced the desired results; and it is incumbent upon us to inquire into the cause. Trade schools of many kinds have been started in different parts of the country, and industrial training has been further developed in the public school system, yet we find ourselves face to face again with the fact that the further expansion of the industries, especially in the mechanical trades, is endangered on account of an insufficient supply of skilled mechanics. Whom can we call to account for this state of affairs? I feel inclined to find the cause of this industrial predicament largely in the attitude of the manufacturers themselves.

5 The leaders of industries (managers and engineers) have not been sufficiently interested in this important matter; and they have not joined forces with educators in giving to the youth the very equipment which the industries demand of him. The burden has been upon the schoolmaster, who, largely confined within the four walls of the school room, has worked out his problems with pedagogical exactitude, according as he perceives the life needs of the boy; but not being himself engaged in practical industrial work, he has not been conscious of the rapidly changing forces that determine the character of industrial life. The manufacturer, in the midst of the bustle of business activity, on the other hand, is confronted day by day with the inadequacy of preparation for practical work of the great body of industrial recruits. He knows the peculiar requirements and therefore should take the initiative to a large extent in coöperating with the schoolmaster in his efforts to provide an adequate industrial training.

6 Manufacturers in general do not realize their present responsibility. Years ago, before vocational training entered into the school system, they applied themselves to the task of initiating boys into the trades; and the results achieved through their efforts seemed to meet the conditions of that time.

7 The old system of apprenticeship, once universally extant, solved the problem well. A boy was apprenticed to a journeyman who taught him a particular trade until the boy became sufficiently skilled to take and hold his place by the side of his master, who himself was an all-round artisan. The artisan of all-round skill, however, has been gradually supplanted by the specialist, skilled in one particular operation only, and consequently the old system of apprentice-

ship has practically become extinct. Under the methods of specialization, manufacturers employed larger numbers of semi-skilled and unskilled workers, and became less alert to the necessity of manning the complicated specializing machinery which came into use with men of higher skill, and of marshaling the large army of specialists with men of a more thorough all-round training and a higher industrial intelligence. This lack of foresight, however, soon showed its effect on the personnel of the working body, and called attention to the immediate necessity of providing a means for the constant renewal of the supply of skilled workers. Manufacturers found themselves confronted with the serious problem of reconciling the discrepancy between the educational equipment which the boy receives in the school, and the vocational equipment which the industries demand of him.

8 They became thoroughly aroused to the importance of this question, and looking back to the old apprenticeship system, began to revive it along changed lines to suit the new industrial conditions. Much progress has been made in this respect in the last few years, even to the extent of combining with the practical shop work theoretical education given in the factory for the purpose of producing an artisan of superior make up.

9 A significant example of this modern training by manufacturers is to be found at the Lynn Works of the General Electric Company. The undoubted success of this apprenticeship system and the novel features which it contains justify a brief outline. This system offers to boys with a grammar school education, who are at least 16 years old, an opportunity to learn a trade. Great care is exercised in selecting applicants and a further weeding out process takes place during the trial period of about a month or two—the initiation period of every apprentice. Those boys only who during the trial period give proof of native ability for the trade which they wish to learn, and who are of the general mental and normal make-up that will insure the probability of their becoming skilled artisans, as well as assistant foremen and foremen at some future time, are allowed to sign the regular apprenticeship agreement.

10 The latter provides for a service of four years at stipulated wages along a progressive scale, which is set with a view of making the boys self-supporting from the beginning—even during the trial period of service. In round figures, the compensation is $4.50 per week during the trial period and the first six months; $5.60 per week during the second six months; $6.70 per week during the second year; $7.80 per week during the third year, and $9.25 per week during the fourth

and last year. A cash bonus of $100 is paid at the termination of the course, and a "Certificate of Apprenticeship" is given to the boy at that time.

11 It is the aim of the General Electric Company to train skilled artisans in the various trades of machinist and tool maker, carpenter and pattern maker, iron, steel, and brass molder, instrument maker, and electrical worker, in such a thorough manner that the leading positions in the factory, such as assistant foremen, foremen, master mechanics, and superintendents may be filled from the ranks of graduated apprentices.

12 It is obvious that such leaders must possess some information besides the practical knowledge of the trade—an industrial intelligence, which has been admirably defined by the Massachusetts Commission on Industrial and Technical Education as: "Mental power to see beyond the task which occupies the hands for the moment to the operations which have preceded and to those which will follow it—power to take in the whole process, knowledge of material, ideas of cost, ideas of organization, business sense, and a conscience which recognizes obligation."

13 In order to gain this result, the General Electric Company has correlated with its purely trade instruction at the machine a theoretical training of an eminently practical character, designed to supplement and amplify the former, so that the boy may be able to apply in the workshop the knowledge which he gains in the schoolroom.

14 Every apprentice receives instruction in the class room for six hours a week during ten months of the year, no school instruction being given during July and August. This enables the boys to take a week's vacation in the summer without conflicting with their school work. The school rooms are close to the workshop, and the sessions are held during working hours, arranged in such a way that about one-fifth of the apprentices are at school at one time. The boys are paid the same wages during school hours that they would receive while working at the bench or at the machine. The object of this is to make them feel the importance of an education; some of the boys might otherwise be unwilling to obtain an education at the sacrifice of wages.

15 After all, we must not forget that these apprentices are only young boys of limited breadth of view, some of whom perhaps have left school because it has become drudgery, others because of the necessity, due to unfortunate circumstances, to earn a living, and still others on account of a craving desire for money making. We must

be lenient with this latter class who would prefer the hours in the shop with immediate returns in money to the hours in school with a remote promise of larger returns.

The desire for education is latent in every boy, to a smaller or larger degree, and needs only some stimulus to bring it to the surface. The payment of a compensation during school hours offers this stimulus. The company in the long run gains by this expenditure in that it develops for itself more efficient workmen.

16 The teachers in the schoolroom are men selected from the staff of engineers, draftsmen, and foremen of the General Electric Company, who are assigned for six hours a week to the work of teaching. These teachers are chosen not only for their good standing in their own profession, but also for the pedagogical qualifications which they may possess. It is obvious that these men are better acquainted with the needs of the factory, and of the industries in general, and can impart more practical instruction than educators far superior in pedagogical attainments, who have not had the advantage of the close touch with industrial activities.

17 The teachers meet fortnightly at faculty meetings to discuss the work of the school and the individualities of the pupils, for the purpose of maintaining a correlated system throughout the class rooms, and at the same time deciding upon the individual teaching that each boy requires.

18 The subjects which comprise the course of studies are: mathematics, physics, technology, and mechanical drawing. For the purpose of this paper it may not be necessary to go into the details of the interesting school program which has been described fully in articles previously written by the author of this address. It may suffice to call attention to two points, which will at once appeal to the manufacturer for their practicability.

19 The teaching is preëminently concrete, and applicable to factory conditions. The young mind can more readily grasp problems of a concrete nature. By selecting them from the actual occurrences in the factory, there is the double advantage of initiating the apprentices into the technicalities of the business, making them acquainted with the different kinds of apparatus manufactured and the different materials used; and of familiarizing them with the solution of the very problems which they will meet later on as journeymen and foremen. The figuring out of the cubical contents of a cylinder of given diameter and length is a purely mathematical problem of mental discipline in which chiefly the memory is called into play; it becomes, however, an interesting problem which demands also the

exercise of the thinking faculty if it is stated in the following manner:

"An order calls for 25 steel pins each to be $\frac{1}{2}''$ in diameter and 2" in length. The pins are to be cut from a rod of cold rolled steel and the tool used in the cutting-off machine will waste $\frac{1}{32}''$ of material between each two pins. How many pounds of cold rolled steel are required to fill the order?"

This is a problem which is met with in everyday factory work and involves nothing but plain multiplication and addition in its solution.

20 Study thus becomes a thing of life importance to the boy; and the teacher keeps this interest awake by presenting, wherever possible, the objects of which he speaks, and explaining their character and usefulness.

21 The second point worthy of note is the part which mechanical drafting plays in the program. This is taught, not for the purpose of developing mechanical draftsmen, but as a means of teaching the designing of tools, jigs, and fixtures needed for manufacture on a large scale. The public school system does not, and for that matter cannot, teach tool designing; and even the higher institutions of technical learning do not give due consideration to this subject, which is a very important requisite for the future mechanical engineer and shop superintendent. These, as well as the skilled mechanic, ought to possess the ability to sketch out the special tools, jigs, and fixtures that may be required from time to time for labor saving manufacture. It is not so much a question of executing fine drawings that may be used over and over again, as in the case of the manufacture of a standard article, as it is a question of sketching quickly, for the immediate use of the machinist and tool maker, a required tool which when once made is expected to remain in use for a long period. Mechanics who possess this ability of combining the work of the tool maker with the work of the tool designer have added considerably to their assets, and have, therefore, become more valuable to their employer.

22 The General Electric apprentice is being educated along these lines, for which reason a large amount of the time set aside for instruction in the schoolrooms is devoted to the teaching of tool design in the upper classes. At this stage of the course, the apprentice has had several years of practical work in the shop, and therefore understands what is wanted of him and appreciates the value of designing jigs and fixtures with a view of saving every minute in the handling of them. The apprentices are given by the teachers a machine part, for instance, or a drawing of it, with the instruction to design a jig or holder, by means of which the various holes in the part may be drilled accurately

and quickly without the necessity of laying out each hole separately and employing high skill for the operation. Each apprentice will present a different design which brings out his mechanical ingenuity, and this gives the drawing teacher a valuable help in developing the individuality of his pupils.

23 Examinations on the school work are held frequently during the year, and a final examination at the end of the course determines, to a certain extent, the standing of the apprentice, and the wages which the company considers commensurate with his value as a journeyman.

24 The other element in this consideration is the degree of skill acquired by the apprentice through his shop training. The methods of training employed are of paramount importance in developing this skill, and it is this feature in the General Electric system which is of peculiar interest. Its adoption was the outcome of a study of the prevalent weaknesses of the present systems of apprenticeship. In most of these, boys are hired by the employment department and indentured for a number of years. They are assigned to one of the shop foremen who is instructed to initiate the young recruit into the trade which he desires to learn.

25 The foreman utilizes the apprentice at first for an errand boy, and for similar duties, giving him after a time simple work at the bench, such as chiseling, and plain filing in a machine shop, shellacing and sandpapering patterns in a pattern shop, making simple cores and cleaning small castings in a foundry; or letting him assist the stock-keeper in the handling of the small tools and the stock materials. There is a certain amount of value in all this work, in that it makes the boy familiar with factory life, accustoms him to the factory atmosphere, and gives him some elementary knowledge of his trade; but after a time the knee in the curve of value is reached, and a further expenditure of time gradually becomes more and more disproportionate to the additional advantage gained. The bright and ambitious apprentice realizes when the knee in the curve is reached, and begins then to press the foreman for higher grade work, especially work at the machine. And so the apprentice step by step has to push himself forward in order to learn the different classes of work, and become acquainted with the operations on the different machines in the department. In general, the foreman is apt to be slow to give the boy the advantage of a variety of training; for if the boy is inefficient at some particular work, he will naturally be held at that work for improvement, and if he is efficient, the foreman is prone to keep the apprentice at the work for an undue length of time, in order to get the greatest commercial advantage from the boy.

26 Here lies the conflict between the purpose of the apprentice and the foreman. The boy comes for a training; he wants to secure all possible information in the shortest time, and therefore desires a variety of work in the department, and an opportunity to work in all departments of the factory. The foreman, on the other hand, representing the company, strives for economy, for cheapness of production, and he can better further his ends by keeping the apprentice at one class of work and in one department for a long time. Few foremen combine with this legitimate care for their own interests the proper appreciation of the boy's object. Of course we must acknowledge that there is a certain advantage in obliging the boy to forge ahead for himself against the difficulties which have been enumerated; for in this way the weak and undeserving will fall by the wayside and the fittest only will survive. Over against this, however, we must admit that many apprentices who succumb to this unequal struggle would under more advantageous conditions come out victorious.

27 Realizing this, some manufacturers have employed a suitable man to look after the apprentices during the whole time of their course and to assist the foremen in giving the boys an adequate industrial training. This overseer, as we may call him, jointly represents the interests of the employer and the apprentices; and to the extent to which he possesses breadth of view he will fulfill this dual function to the advantage of both. In many instances his interest in the boys will lead him to inaugurate evening classes for the study of mechanical drawing, mechanics, and kindred subjects, and even perhaps to influence them in their leisure hours.

28 A system of apprenticeship along these lines is a decided step forward in the right direction, but it still contains one important defect in common with the system first outlined.

29 In either case the apprentice is the pupil of whomever happens to be foreman, assistant foreman, or leading journeyman in the department to which he has been assigned. These men have been selected for their skill, and not on account of any special fitness that they may have for instructing boys. It is well known that few people in whatever walk of life, with the exception of professional teachers, are qualified to impart information in a satisfactory manner, though they may themselves possess this knowledge and may well be able to apply it to their work.

30 The drawback under which the boy thus labors is often further intensified by the productive requirements in commercial manufacturing establishments. Some departments, for instance, may have only

a small amount of work on hand and of such a nature that it will not add to the boy's skill and knowledge; while others may be crowded with work of an instructive and interesting character. The boy who happens to be assigned to the first department is, therefore, put at a decided disadvantage over the apprentice in the other department where productive conditions offer a splendid opportunity for his further advancement. The realization of these weaknesses in the systems of apprenticeship leads to the remedy that should be applied, which is to equalize the opportunities of all apprentices, and to afford them the most expert instruction in the practical work of the trade, especially during the first part of their course, for a solid or faulty foundation determines the strength or weakness of the whole structure of achievement. The General Electric Company has proved the validity of this remedy.

31 Four years ago it started as a special department devoted entirely to the preliminary, practical training of the apprentices a small shop in the big factory organization, directly under the control of the man in charge of apprentices. Beginning in a small way, this "Apprentice Training Room" has grown in size and equipment until today it covers an area of about 10,000 square feet with a tool equipment of 105 representative machines. There are 20 drill presses of various sizes, 4 speed lathes, 1 pulley lathe, 1 turret lathe, and 44 engine lathes, some of which are belt driven, while most of them have individual motor drives. These engine lathes vary in sizes from 12 inch swing and 5 foot bed to 20 inch swing and 8 foot bed, and are fitted up partly with plain rest or rise and fall carriage or compound rest and partly with taper attachment suitable for tool work. There are also two 24 inch planers, nine 15 inch shapers, one 42 inch vertical boring mill, two plain and two universal horizontal milling machines, one vertical milling machine, one centering machine, one spliner, one wet grinder, two universal grinders, one surface grinder, four tool grinders, one hack saw, two arbor presses, one bench watchmaker's lathe, besides a number of small electric bench drills, buffing and polishing motors. Then there are, of course, the necessary small tools, such as drills, taps, reamers, chucks, and arbors, besides 40 vises.

32 Most of the machines are of the latest and most improved type, while some of them are second-hand tools, a few of which have even been rescued from the scrap heap. There is a twofold purpose in the use of old machines—the economic and the educational; it prevents the abuse and injury of high priced modern machinery, which is apt to occur with boys who have not had experience in the handling of machines, and it affords an opportunity for repairing ma-

chine tools, which is undoubtedly the best training that can be given to a future mechanic, since it develops the ability to do things, thoughtfulness, and self-reliance. Some of the old lathes have thus been provided with new gears, the spindles have been turned down, the bearings rebabbitted, or some special attachments have been added until they have been made practically as useful as some of the expensive modern lathes. A stockroom of suitable size occupies one corner of the training room and is conducted in the same manner as a stockroom in any well managed manufacturing establishment. This equipment is large enough to instruct about 125 boys at one time. Usually about 15 of these are applicants serving their trial period, while the rest are regularly indentured apprentices on their first and second year of service.

33 The man who has charge of this training room is an ingenious mechanician, who has himself served an apprenticeship, has had charge of men and work, possesses the ability and patience to instruct beginners, and is peculiarly adapted to this kind of work. He interviews all applicants, and with a keen insight selects those who are to be admitted to the trial service. This gives him an opportunity to study carefully the boy's mental and moral make-up and his native ability for the chosen trade. A painstaking and encouraging attitude toward one, a severe and almost threatening arraignment of the other will bring out very often latent qualities that might not come to the surface except for this individual treatment. The careful selection of those who are to be admitted to full apprenticeship is a very important function of the shop instructor, in that it determines the personnel of the apprenticeship system. Under the stipulations of the contract, the General Electric Company has a right to terminate the service of any apprentice at any time for good cause, such as improper behavior or inefficiency of work; yet in accepting the boy for regular apprenticeship and indenturing him, the company has assumed a moral obligation for the development of the apprentice which it cannot very often cancel without forfeiting the faith and confidence of the public.

34 The instructor initiates the apprentices into the trade and lays the foundation for their future skill and efficiency. It is his duty, wherever possible, to inaugurate with the apprentices labor saving methods of manufacture, and to make and use labor-saving devices which thereafter will be accepted by the other factory departments. He can without difficulty develop the highest practical cutting speeds and thus set a standard in this respect to the whole factory organization. The training room stands for the best and most efficient methods, and is not hampered in its development along these lines by a

hostile attitude which may be encountered in factory departments on the part of regular workmen, which is usually due to ignorance or misunderstanding of the true conditions. The shop instructor has two assistants, this small number being made possible by carrying out the policy of utilizing most of the apprentices themselves for assistant instructors. After an apprentice has learned thoroughly a certain operation, turning of pulleys, for instance, he is usually required to break in a new apprentice on this kind of work before he himself is taught another operation, boring, for example, by an older apprentice who has already learned this operation.

35 In this manner, the apprentice is pupil today and teacher tomorrow, then pupil again and teacher once more. The advantage of this policy is obvious. It develops early in the apprentice the faculty to instruct, and keeps him wide-awake in his work. The young master will put forth his best efforts to impress the young recruit with his own achievements and the latter will often not hesitate to ask his boy teacher questions that he may not, out of false pride, ask the regular instructor. Couples of boys may, therefore, be seen in the training room almost every day. A study of their instructive and receptive efforts is quite interesting. Some of the apprentices are required to spend a few weeks in the stockroom and learn stockroom methods, or act as clerks to the shop instructor in order to become acquainted with the clerical duties of a shop foreman; the making out of time cards and reports, the ordering of raw materials, and the shipping of finished goods. The object of all this training is to make real workmen, and this can be achieved only by carrying on real work. All production in the training room, therefore, is of a commercial value.

36 The General Electric training room makes cast iron pulleys of various sizes and design, clutch pulleys and flange couplings, small and large parts of regularly manufactured machinery instructive in the teaching of turning and boring, drilling and grinding, planing and shaping, milling and slotting; it manufactures shafts for fan motors and power motors, and spindles for various purposes, and finally produces not only the special tools, jigs, and fixtures needed for its own use, but also many of those required for other factory departments. The psychological value of commercial work is of great importance; it takes the boy out of the sphere of laboratory work into that of industrial life; it clinches the boy's interest, inasmuch as it makes him realize that the product of his work is to be a part of some useful machine, rather than a plaything or an object of exhibition in some show case. The possibilities of apprentices under proper instruction, having the

right interest in their work, are remarkable. Almost every week brings new surprises in the General Electric training room at Lynn.

37 A training room similar to the one just described for machinist apprentices is maintained for the pattern-maker apprentices. This has a less complete equipment of its kind, however, on account of the smaller number of boys indentured for this trade. This condition may be improved at some future time by enlarging the machinist training room through the addition of a suitable pattern shop equipment.

38 The General Electric Company has only a few foundry apprentices who are instructed in the regular foundry. It stands to reason, however, that a sufficiently large number of foundry apprentices would justify the installation of a foundry training room.

39 A separate building with foundry, pattern-maker, and machinist training rooms, with the class rooms on the top floor, would be the ideal trade school in the factory.

40 After the apprentices have spent from 1½ to 2½ years in the training room, according to their individual ability, they are transferred to factory departments where they serve a post-graduate course for the remaining part of their apprenticeship. They learn here accuracy and speed on a greater variety of work, and have an opportunity to specialize in die-making or tool-making, or laying out machine work for which they are best suited. The apprentices are now under the charge and discipline of the respective shop foremen and have to all intents and purposes taken their places beside their shop mates, although they still attend the apprentice school. The shop instructor, however, retains his interest in the apprentice whom he may transfer from one department to another, either at the request of the foreman or the apprentice, or whom he may even take back temporarily to the training room, either for the good of the service or for the rectification of some defect that the boy may have developed in his work. If a disagreement between a foreman and an apprentice arises, the shop instructor acts as a mediator. He considers the apprentices as his boys and looks upon them in that light even after they have become journeymen. He passes final judgment on the apprentice when he determines the standing to be recorded in his "Certificate of Apprenticeship."

41 The General Electric Company encourages all graduated apprentices to remain in its service and, as previously stated, hopes that in due time most of the assistant foremen and foremen in the factory will be graduated apprentices. Some of those who have shown a special ability in their drawing work in the class room are appointed as tool designers in the drawing office, where their combined knowl-

edge of tool making and practical tool designing puts them far ahead, in this line of work, of even college educated but not shop trained draftsmen.

42 Up to this date 467 boys have been admitted to the trial service and 316 of these have been indentured as apprentices. Of the latter 37 have terminated their contract with the consent of the company on account of sickness, removal of the family from town, or other good reasons; 37 have broken their contract by seeking other employment during their apprenticeship, and 22 have been discharged for good reason. Of the remainder, 34 have graduated; 186 are still on the apprenticeship course, and 26 are serving their trial period. Of the graduates 28 are still in the employment of the General Electric Company at Lynn, and most of those who have sought other employment will sooner or later return to their alma mater.

43 Very often the graduated apprentice with the hundred dollars cash in his pocket determines to seek employment in some other place in order "to see something of the world," as he puts it. Such desires should not altogether be discouraged; it will often do a boy a great deal of good to get among strangers, and the rubbing up against the world will take off the rough corners, and round him out into a fuller and better man.

44 The success of the General Electric plan is not peculiar to the conditions which exist there; it can be applied in a more or less modified form to any manufacturing concern of suitable size. Its establishment should be encouraged, since it benefits alike the apprentice who obtains an excellent industrial training and the employer who not only develops efficient men for himself, but does it at no financial sacrifice, on account of useful work performed in the training room. The picture of a well equipped training room suggests another thought in carrying out the plan to provide for a constant supply of skilled workmen. It has often been pointed out that our public school buildings with their expensive equipment ought to be used for more than six hours a day, five days in the week and forty weeks in the year. This contention has led to the social utilization of the schools for evening classes, public lectures, parents' associations and neighborhood clubs. May we not begin to point to the uneconomic condition under which large factory buildings with their costly equipment are left idle from six at night until seven in the morning, and in many cases from noon on Saturdays? Cannot these factories be utilized during these idle hours for industrial extension work for the benefit of the people without expense to the employer? The training room affords an excellent opportunity for a beginning. It is

a self-contained department with a full equipment necessary to learn the machinist's trade in all its principal branches; and, as a rule, work left in the machine at the close of the regular factory hours is not of as expensive character as may be found in ordinary machine shops, where the removal of it from the machine may seriously interfere with economic and quick production.

45 This training room could, therefore, be opened from seven to ten at night, and on Saturday afternoons, to those employés of the company who desire to learn the machinist's trade or some part of it. There are undoubtedly many ambitious workingmen, who on account of lack of education and skill or through thoughtlessness in their younger days are now occupied with unskilled labor with no apparent chance of rising either in position or in wages. They may be anxious to improve their condition by learning to do work on a lathe, planer, shaper or boring mill, or on several of these machines. What opportunities have such men now for gratifying their ambition? Some through perseverance may persuade their foremen to put them at one of these machines where they would receive more or less superficial instruction. They have there a chance to earn somewhat increased wages, especially if they become experts on one machine. Further advancement is probably precluded.

46 Some workmen are fortunate enough to live in one of the few cities in which evening trade schools have been established. But what about the great majority of unskilled workers who could acquire some skill, and thus rise from a lower to a higher industrial efficiency, if they had an opportunity to be instructed in practical work during their leisure hours? Let these men in the factory come together in small classes for learning to do such work as their ambition dictates, and utilize the training room for three evenings a week. The shop instructor of the apprentices with able assistants may well take charge of this evening training for which he, of course, would receive extra compensation. The instruction should be thorough in regard to the work on the machine as well as the machine itself, and those only who satisfy the shop instructor of their ability should be allowed to remain. Fairly good lathe, shaper, planer, or borings mill hands can be turned out after six to nine months of evening instruction, and universal milling machine operators in about a year's time. Those who satisfactorily complete a special course should be given a Certificate of Special Apprenticeship and for each subsequent additional course completed an additional certificate should be issued.

47 The work in the evening classes should consist of regular factory work and the value of properly finished pieces to the company

would probably offset the expense of heat, light, and power, wear and tear of machinery and small tools, and spoiled material. A small tuition fee of perhaps three dollars a month would pay for the salary of the instructor and his assistants.

48 This is only a brief outline of a plan which can be worked out as an excellent investment for the workman who thus increases his earning capacity, and for the employer who adds to his supply of skilled workers. One can readily perceive how many a workman through close application to several years of practical evening instruction may develop into a skilled mechanic even though he has not had the advantage of an apprenticeship training. The possibilities of the one are as great as those of the other.

49 We have so far considered ways and means by which an employer may provide for a constant supply of skilled workmen for his own benefit. What can be done by the individual for himself can undoubtedly be accomplished for the industries in general by the right man and the right methods. It would necessitate the separation of the training room from the individual factory, and its establishment as an independent institution in a place where its work could be of benefit to the industries of the locality. The day course would have to be elaborated upon in order to include what has been previously termed the "post-graduate course in the factory," so that the apprentices may go from here directly into the industries as full fledged journeymen. There are advantages and disadvantages in the independent school shop as contrasted with the factory training room.

50 The school shop will be able to attract a desirable class of boys who would gladly enlist in an institution of a vocational character, but would not care to enter upon an apprenticeship course in a factory. The lack of respect for mechanical work on the part of the American youth is responsible for this state of affairs. There is the other marked advantage of having an institution that is centered on one interest—the training of efficient workmen. On the other hand, the school shop has not the amount and variety of work right at hand which obviously the factory training room can command at all times. Able business management, however, will overcome this difficulty so much the more readily as manufacturers have a selfish object in furthering the aims of the school shop; the latter must also provide for the design and manufacture of an easily salable article that can, therefore, be produced for stock at such time when other commercial work cannot be obtained in sufficient quantity.

51 The standard of the school shop must be of the highest, so that it may commend itself through the excellency of its graduates, both in

the day and evening classes, to employers, employés, and the public in general. A high standard must be maintained in the practical shop training as well as in the purely educational work. The latter may be conducted along the lines worked out by the General Electric Company, or it may be placed under the charge of the public school authorities, who, after all, are responsible for giving the boys the training which they need to make them self-supporting members of the community. The State would also infuse a sufficient amount of the cultural element to develop the boy at the same time into a man and a law-abiding citizen. This latter plan, however, could only be carried out if the school authorities of the town in which the school shop is located would consent to the establishment of a special school course, offered at such times of the day when a part of the apprentices could be spared from the school shop. The special school program would have to be worked out so as to meet the demands of the industries and would have to be taught by properly qualified teachers whom we might term, "industrial instructors." Until such conditions prevail, the school shop will have to look after its own educational work. Proper conditions may be brought about quickly in Massachusetts, for instance, through the coöperation of the management of the school shop and the Massachusetts Commission on Industrial and Technical Education. The Commission was appointed recently for the purpose of studying the industrial needs of the State and of establishing industrial courses and trade schools that will answer these needs. The school shop could serve the Commission as a laboratory, in which they could work out jointly with the manager of the same an adequate industrial training of the boys.

52 Under this combination the school shop may be run as a commercial, profit making establishment without any injury to the educational development of the apprentices but with some advantages which an educational institution of even a vocational character cannot offer.

53 In this address I hope I have stimulated interest among the manufacturers in the subject of providing for a constant supply of skilled workmen, and trust I have indicated a possible plan that will readily lend itself to the solution of the problem under existing conditions.

DISCUSSION

MR. H. F. J. PORTER: It is very necessary for us to understand that the motive for giving shop instruction to our workmen is not by any means philanthropic in its nature. It is on the contrary solely a business one, for the purpose of strengthening our working organization that we may get from it a better and cheaper workmanship.

2 To accomplish these results I think I can show that we must not only educate our employees but *we must try to hold them in our service afterwards* for it is perfectly evident that if after we have educated them they go elsewhere our efforts to improve our working conditions have been futile and should they go to a competitor we have actually spent money to our own business detriment. I think that the General Electric Company has not sufficiently emphasized this point in its curriculum, for although (in paragraph 41) Mr. Alexander states that it encourages its apprentices to remain in its service, still further on (in paragraphs 42 and 43) he shows that nevertheless there is a strong tendency for them to leave, in fact a very large percentage do leave. It seems to me that these boys should all understand that they are in line for advancement for better places than they could hope for elsewhere, and that if they go away they will lose their turn. I fear that Mr. Alexander's wish is father to the thought that those who leave will return, but the probabilities are as great that they will not, nor will it do for him to excuse this defect in the system by saying that they will be benefited by rubbing up against the world. If he has taught them the best way to do things, it ought not to be supposed that they will find any better way outside, while on the contrary they will see many other ways which are worse so that with their lack of experience and at their impressionable age if they do come back they will have learned nothing good and a great deal that is bad.

3 Now, we know that education is a very expensive luxury. This is shown by the appeals for funds made by our educational institutions all over the country to help them carry on their work. So that it is quite possible that a manufacturing enterprise may go into an elaborate system of industrial education and find that the latter would not only fail to accomplish what is desired, but might actually involve the company in financial difficulties by the attendant expense, especially when it is working on the small margin of profit which the close competition of the day makes necessary.

4 I want now to give some evidence which will bear me out in my assertion that manufacturers are not accomplishing what they are

striving for by simply establishing in their shops apprenticeship systems or other systems of educating their employees. I shall mention a few concrete instances which have come under my own observation, as examples.

5 In a works in Pittsburg, of which I have some knowledge, there had been a large financial loss for several years, owing to poor business management on the one hand and an inferior class of employees on the other. Under a new business administration improved working conditions were introduced in the factory, with the result that a better class of employees was attracted there. Now, these works were dominated by the same interests which controlled a very much larger works near by, where an expensive apprenticeship system had been instituted and kept running for several years.

6 Under the conditions established by the new management in the smaller works the attraction became so strong that employees from the larger works were drawn there, which brought a protest from the management against taking away the graduates of their apprenticeship system. The opportunities for advancement were so superior in the smaller works that they acted as an allurement which the larger works had provided nothing to offset. In fact, it was the policy of the latter to fill its best positions from outside sources instead of from its own organization. The effect of this policy was to destroy all hope of advancement among its employees and everyone who had any ambition to better himself went elsewhere as soon as he got his equipment. I had previously heard that these works were educating mechanics for other concerns all over the country and I then had the evidence presented to me at first hand. No effort was subsequently made to close the gates at the larger works and the exodus went on as merrily as ever so that the only effect of the protest which had to be heeded was to preclude the smaller works from enjoying its share of the benefit.

7 In a works near Philadelphia, of which I have more recent knowledge, a slightly different condition existed. The works were situated in a beautiful suburban district, the wealthy residents of which did not want a factory, nor workmen's houses located near them, nor did they want any trolley lines in their vicinity. The result was that the workmen in order to reach the works at 7 o'clock in the morning had to arise at 5 o'clock and sometimes stand up in the cars for three or four miles and then walk a mile and a half from the nearest trolley and steam railway, so that they had actually done a half day's work before they started in at the factory.

8 Good mechanics could get work elsewhere which did not entail

such inconvenience of access; consequently, it was only an inferior class of workmen who could be persuaded to go there. Now these men had to be educated after they went there in order to perform their work satisfactorily, but it was found that they stayed only long enough to acquire sufficient knowledge to equip them to enter other works of the same kind in the city proper. In fact, it got to be known as a feeder for a large locomotive works there.

9 I happened to be at these works for the first time last Easter Monday. Now Easter in Pennsylvania is a notable festival, the effects of which often last over till the next day, and when I arrived at the works in the morning with the manager, the superintendent greeted us by saying that he thought he had better shut the works down for the day as there were too few men present to run them economically, and that many of those were not in a fit condition to work. There were then 98 men in the organization and 36 per cent were absent.

10 Since that time working conditions have been made more attractive there. Transportation facilities have been secured. Workmen's houses of an inexpensive but adequate character have been made available and a club house has been opened. At the present time, there are 210 men in the organization and last week, the day after Thanksgiving a genuine holiday, only six per cent were absent. Several of the absentees were away by permission and there was no evidence that those present were not fit to do their full duty. In other words, in six months the organization had increased more than 100 per cent and the absentee question was no longer a live issue. I mention this incident to show the effect of a change in management on the character of the organization. It is not necessary now to maintain the system of education previously established. The helpful features of the place are strong enough to bring back not only old hands who had been educated there, but graduates of apprenticeship systems of other works come there as well. These men are good enough mechanics for the work in hand and they stay.

11 Again, take a works in this city with which I am familiar. The proprietor this fall told me that it was very difficult to get good workmen, that the labor market in New York contained only floaters, all the good mechanics going to the nearby manufacturing towns. I told him I thought that if his inducements were strong enough he would have no trouble in getting as good mechanics as he wanted. He asked me to visit the plant, which I did. The manager there told me that he had an average loss from his organization per month of 15 per cent or 180 per cent a year. He said there were 700 men in the

organization and that as many had [illegible] the works during the summer months alone. Now every one of the workmen who came there had to be educated more or less to do the special work in which the plant was engaged, all of which was being lost to it, its benefit going to others. Changes were at once instituted in the character of management which are now rapidly reducing the percentage of losses.

12 A large and representative works of which you all have knowledge has over 4000 men employed. It has an apprenticeship system which has been described in the magazines as being very advanced and complete and I have no doubt ranks with the system at the Lynn works. My information of conditions there is as recent as last week when one of the officials told me that the percentage of loss of employees is from 8 per cent to 10 per cent per month, or up to 120 per cent per year. This should not be construed to mean that the entire personnel of the working force changes every year, for a very large number remains permanently, but it means that nearly 5000 men, which is more than there are in the whole organization, pass through the works every year, each having received a certain amount, and I know from the character of those works that each would receive a large amount of personal attention, supervision, and education, all of which are extremely costly. Now, if a company, run under good business management should lose a large portion of its plant during a year by being washed away by a stream which flowed by its side it seems to me that a great effort would be made to prevent a recurrence of such a disaster. And there is all the more reason for summary action when the stream of humanity that flows by a works carries away such a large part of the working organization. Recognized authorities on management have emphasized the importance of upholding the integrity and solidarity of the working organization.[1] There is nothing so expensive to a company as constant changes in the personnel of its working force. It seems to me that the weak point in our systems of Industrial Education is in not laying our foundation deep enough.

[1] In my paper No. 1101. Vol. 27, on "The Realization of Ideals in Industrial Engineering," presented at the last annual meeting, I quoted Mr. Andrew Carnegie as saying that: "Should some great catastrophe destroy all of his mills, but spare his organization, which had required many years to perfect, he might be inconvenienced temporarily, but that he could depend upon his organization to re-establish his business. If, however, he should lose his organization, even if his mills were the best in existence and were left intact he would not have time nor strength to rehabilitate himself in the business world."

13 To my mind it is necessary, by the adoption of the simple means included in the term "Industrial Betterment," first to increase the *attractive force* in a works in order to bring to it a better class of men, and second to develop a *cohesive force*, to hold them there. Then you can educate the organization to good and permanent effect. In order to develop these forces you must teach the owners and managers of works the economic value of industrial ethics that they may appreciate the advantages to be derived from fair treatment and comfortable and sanitary surroundings in order that men may be kept contented and in good physical condition for permanent service. In too many factories there are men and women overworked and underpaid and otherwise unfairly treated. Too many factories are dark, cold, unventilated and otherwise unsanitary. All the education in the world that you can give your employees will not bring about in these places the results contemplated. Such conditions should be prevented as well as cured and to bring about improvement in this direction intelligently, it seems to me that we should begin by having our schools and colleges educate our boys, who later may become factory owners and managers, in such a way that they will take into account the human element in business.

"The conscience which recognizes obligation" which Mr. Alexander mentions (in paragraph 12) should be developed in the management as well as in the working organization.

14 The Society for the Promotion of Industrial Education, which our Mr. Higgins has just launched so successfully, held a meeting at Cooper Union, at which one of the speakers referred to a point which your President has brought up, viz: the severe competition of our country with Germany, and asked if it was not a fact that Germany, before she had established her industrial school system, possessed a deep realization of the value of the ethical treatment of her working people and had encouraged them to live a healthy, thrifty, and moral life so as to develop into strong, happy, and contented working men and women.

15 Afterwards she saw to it that they were given sanitary and cheerful working conditions and then, but not till then, did she educate them. When we realize as deeply as Germany the true value of the full and willing service of a man, I think that in the industrial tug of war between that country and ours, we will then and not before be able to pull the marker over to our side.

MR. MILTON P. HIGGINS There is nothing so important to the manufacturer and to the workman himself as the provision for a supply of skilled workmen.

2 The future of American industry is more dependent upon a supply of skilled mechanics than a supply of any other class of men. Engineering colleges have accomplished more than ever was expected, in producing a large number of men for educated mechanical engineers. The engineering graduate is every year more and more of a professional engineer, and less of a skilled mechanic. Still the mechanical engineer must depend upon the machinist for the realization of his plans and ideas.

3 In one Massachusetts town, there are 106 High School graduates in the local engineering college. Each one of these boys went from the ninth grade into the High School with a fixed intent to fit for the engineering college. What about the 106 boys who did not choose to go to college, but stood next to the 106 who were able to take the engineering course? What becomes of this strata of man—material just below the strata from which professional engineers are made. That second strata is more important to our industrial life than any other. These are the boys who ought to learn trades. These are the boys who ought to become skilled workmen. These are the boys who should make the men who can intelligently control the ponderous machine, and guide the tool of precision. What chance have they? The outlook in the ordinary shop and foundry is not bright enough for that grade of boy, because if they go into the ordinary shop or foundry their opportunity of education is cut off.

4 There is hardly a possibility for such a boy to obtain the effective shop skill that he desires, to say nothing of any mental discipline and technical knowledge necessary to his trade. So at present, the boy just below the one who aims to become a professional engineer leaves the ninth grade of school, and drifts from one thing to another, never mastering any trade or business.

5 Is not this state of things deplorable when the positive limitation to American productive industry today is the dearth of skilled workmen? It is of vital importance that effective effort be made to meet this national emergency. It behooves us to hail with great interest every such successful effort as this described by Mr. Alexander at Lynn. I can speak with confidence of this work established by Mr. Alexander, because for years past, I have observed its progress frequently. This gratifying success in training and producing intelligent skilled workmen comes about largely from such facts as these:

It is recognized that industrial education consists of two parts, viz.: skill and schooling—two parts as real and vital as body and mind, two parts of equal importance.

6 At Lynn, they believe that nothing is too good for a boy who is learning a trade—the best tools and machines, the best variety of work, and the best instruction is given the apprentice. Only men who have had experience in training boys for skilled workmen, can conceive of the great possibilities with such boys in the way of making all round skilled workmen in a short time.

7 It is not easy to appreciate what results can be attained in the line of producing shop products of high standard, upon a commercial, profitable basis, by apprentices, under good conditions.

8 It is not every shop that can do this as well as the General Electric Company are doing it, because they are not prepared to establish and maintain a high school as a part of the works, nor is the average shop management prepared to organize and carry on systematic training as it is carried out by Mr. Alexander. With these difficulties in view, I still adhere to the idea of accomplishing these same results in a simpler and surer way—by what I call a *half time school system*.

The public school can and ought to give boys who are learning a trade a high school course of education adapted to their needs and circumstances. So far as text book knowledge and mental discipline are concerned, it is as much the place of the public school to fit boys for the life of a machinist as for any other life. This can be done in a part of the time during the high school period, while the boy is in a training shop similar to the Lynn apprentice shop the other part of the time. The shop training (*i. e.*, the development of shop skill and experience) is the vital part requiring attention in industrial education, and the problem is greatly simplified when attention is concentrated upon this vital part.

9 To do this, it is necessary to have a training shop with the one object of teaching a trade, for example, the machinist's trade. I would first take this trade because it is the foundation of most other trades. The machinist's trade is by far the broadest and most far reaching of all mechanical trades. It is the foundation of all manufacturing, and all mechanical engineering. The difference between the machinist and the mechanical engineer is not a difference of kind, but a difference of degree. We can make no greater mistake than to think that automatic machinery, division of labor, etc., in any way eliminates our need of competent, all round, skilled machinists.

10 Our machinists require a different training and more mental discipline than the machinists of former time, but he fills a more important place than formerly, and the dearth of this high grade machinist is the most positive limit to the advancement of productive

mechanical industry in America. The machinist we ought to produce by our training shops coöperating with the public school, is the man who is to work at the bench and the lathe, and every other spot in the whole realm of industrial works, where intelligent skill counts. The skill of such a machinist should not be confined to a single department of work. He can well afford to be a pattern maker, a molder, and a draughtsman, as well as an expert workman in the machine shop where rapid production and work of the finest precision is required. It has been demonstrated within the past thirty-five years that it is quite possible to produce skilled workmen in a three or four years' course, and at the same time secure a considerable mental discipline. The mental discipline begun upon school book work in the schoolroom continues in the most gratifying way when the boy drops the school book for the work with tools.

11 The thinking workman who studies under right conditions is likely to strengthen his mental capacity by turning to shop work better than is possible in any other way. The half time combination is most effective. It is a great mistake to train large numbers of men for mechanical industry from the top downward. There is always disappointment and failure but if we can begin with the skill of the machinist as a basis, made as broad and as varied as possible but with absolute practical thoroughness in personal skill supplemented with considerable mental descipline, there is no limit to the future advancement of such skilled workmen. This great possibility becomes assured when the training consists of equal portions of school book discipline, and *shop* experience, both halves of the education based upon shop work, and shop experience.

12 In order to do this most effectively, we must enlist a grade of boy who has a love and respect for mechanical work, a boy who can take pride in good work and intelligent skill, a boy who is not ashamed of his calling and vocation, a boy who is not ashamed of overalls, and is proud of clean hands only after a hard, dirty, difficult job has been completed. There has been a sickly, weak shrinking from healthful pride in skillful work. In some cases this weakness has been shown by calling machine shop work "machine laboratory exercises," and by calling the foundry the "molding laboratory." There is no element in the life of a nation that more truly determines its rank in the scale of civilization than the mechanical skill of its artisans. Mechanical skill is something to be proud of—not to be ashamed of—for skill is the counterpart of knowledge, and these two combined constitute the creative power of a people. Even with the great advantages of America, with her abundance of room and material, and with her

organizing and engineering ability, we are not sure of a leading place among the nations, unless we secure more and better skilled mechanics. Our greatest danger lies in the lack of highly trained native mechanical skill. At present, there is an enormous gulf between the professional engineer and the unskilled or highly specialized operative.

13 Our only remedy is organized industrial education, based upon the recognition that practical mechanical skill is the true basis for all this effort. Knowledge and skill must be organically combined in the same man to meet the needs of our industries, but the greatest of these is skill. More knowledge without skill will simply add to the supply of good for nothing people, and skill with insufficient knowledge cannot meet these latter-day demands in our shops and factories.

14 Why have we made so little progress in meeting the needs of industrial education when there is such a prevailing interest in it?

15 It is this: Almost all effort has been directed to means of adding more knowledge, when almost nothing has been done to secure mechanical skill for the boy who is not very deficient in his schooling. There are thousands of evening schools and extension schools for the skilled workman who needs them, but none that fully meets the needs of an intelligent boy who requires thorough practical mechanical skill and experience.

MR. FRED W. TAYLOR No country can hope to hold its own in the severe industrial competition which is to come unless the rank and file of its artisans and mechanics are educated as well as quick witted. I do not, of course, refer to a classical, or even scientific education. I mean a thorough grounding in the principles and rudiments of the trades at which they are working. In giving this type of education to their workers I believe that the Germans are in a fair way to outstrip us, unless we become fully alive to the necessity for this work and active in its accomplishment.

2 There are many different forces and potential elements in this country which might and should be directed toward the attainment of this object.

3 I am looking forward to the time when our trades unions shall be a much more useful element both to themselves and to the whole community than they have been in the past. When they shall be imbued with the spirit of helping their members as well as their employers through the arts of peace rather than the arts of war. When their chief thought may be that of educating and improving their members, and thus rendering them worthy of higher wages,

rather than that of devising ways for forcing [illegible]ployers to make concessions to them. I think the time will come when they will realize that the true and permanent road toward high wages and prosperity lies in so educating themselves as to be able and willing to do more work in return for larger pay, rather than in fighting to do less work for the same pay or the same work for larger pay.

4 However, I feel that we employers as a class need quite as much enlightenment in this respect as to do the working classes, and that we should be brought to realize thoroughly that not only our personal interest, but our duty lies in helping to educate our employees so as to be fit for a higher wage, and then in establishing such conditions as will enable them to get it.

5 The broad minded policy adopted by several of our larger companies, notable among which are the Baldwin Locomotive Works and the General Electric Company, in establishing systems for educating their apprentices, such as described in this paper, is to be highly commended. And I trust that all of our larger companies may in the near future follow their examples.

6 There are some advantages in the plan described by Mr. Alexander, of having apprentices taught in a department by themselves. But this plan is to my mind accompanied by the serious disadvantage that they are not surrounded by mature workmen. They are in competition with boys instead of men, and for this reason lack the most important object lesson of seeing skillful men working earnestly not only to do good work but to do it fast.

7 For our smaller engineering and manufacturing companies, however, in which ninety-nine hundredths of the work of the community is done, an apprentice system such as described is manifestly not possible.

8 As supplementary to the system described in Mr. Alexander's paper, I wish to call attention to a method by which not only apprentices but also those intelligent workmen who have not been so fortunate when young as to have the opportunity of serving an apprenticeship can be taught a trade quite as effectively in our small shops as they are in larger establishments under Mr. Alexander's system.

9 In the paper on "Shop Management," read before this Society in 1903, forming part of Volume 24 of the Transactions, will be found a description of functional or divided foremanship, under which each workman has eight daily foremen over him instead of one.

10 Each of these foremen devotes his energies to one-eighth only of the work in which the ordinary foreman is supposed to be proficient, and as a consequence acquires a competence in his specialty

far in excess of that possible to the old fashioned, all-around man. Under this system these functional foremen are called upon not only to teach but to stand over and train the men under them into a knowledge of how to do their work and also to manual dexterity. The rapidity with which the workmen and apprentices learn under this constant supervision and help is indeed remarkable. And as this system can be established in small shops as well as large, with great profit both to employers and employees, it offers a ready solution to the problem of educating our apprentices.

MR. H. K. HATHAWAY The shortage of efficient workmen, as Mr. Alexander has pointed out, is a problem of such vital importance that unless more attention is given to its solution, the expansion and development that our industries have enjoyed must inevitably be greatly restricted.

2 Every employer knows from bitter experience how difficult it is during times of prosperity like the present to obtain mechanics who are proficient in one branch of the trade, let alone men skilled in all its branches. This scarcity is due to causes of such a complex nature that I will not undertake to enumerate them.

3 Mr. Alexander has pointed out one way to overcome this unfortunate condition, in his description of the training shop for apprentices maintained by the General Electric Company, and it is with great satisfaction that I note that the scale of wages paid is about 50 per cent higher than are ordinarily paid apprentices, and this alone, if generally adopted, would do much to overcome the disinclination that most boys and young men have to serve an apprenticeship and I believe that still better results would be achieved if the wages paid started at about $8 per week and went up by easy stages to $12 per week for the final period. If this were done it would enable many young men between the ages of twenty and twenty-five years who are entirely dependent upon themselves for support, to enter the field of mechanics, and such young men would prove a far greater worth, both during their apprenticeship and afterward, than boys from sixteen to twenty years old. Furthermore, the shorter hours, clean hands, and eight dollars per week of the clerk would not appear to such marked advantage over an apprenticeship to the machinist trade.

4 The trade schools offer a partial solution to this problem, but there are so few of them and the number of students in each is so limited that very little practical benefit can be looked for from that quarter, unless we can have, through the generosity of our millionaires,

many more of them, and I am inclined to feel that this is a much more practical and useful way to get rid of burdensome millions than building libraries.

5 The training shop of the General Electric Company bears a strong resemblance to the trade school and from the fact that it is in close touch with a great manufacturing works, has many advantages over the trade school, and is infinitely superior to the haphazard instruction that is characteristic of the average apprenticeship.

6 I cannot help thinking, however, that there is one serious fault in the system described by Mr. Alexander, and that is in the fact that one man and two assistants are expected to instruct and maintain discipline among 125 boys, to interview and select new recruits, to study carefully the mental and moral makeup of each boy, as well as his aptitude for his trade, and follow up the progress of many other boys who are completing their course in the factory departments. This, it is explained, is made possible by utilizing most of the apprentices themselves for assistant instructors, and is in itself a statement that there is a shortage of men in charge. I do not see how instruction thus handed from one boy to another can be as efficient as it would be coming first hand from a competent and experienced instructor, and it is obvious that the progress of each boy must be seriously impeded by this method.

7 Unfortunately, however, the training shop plan is entirely out of the question for the average small manufacturing plant, and their solution must come from another source. Mr. Taylor's plan of functional foremanship, seems to offer the best solution to the problem of supplying the demand for efficient workmen, and I believe that if it were applied in the General Electric Company's training shop, the good work being done there could be greatly enhanced, the instruction made much more thorough and accomplished in a much shorter time.

8 I have had the good fortune to be occupied, during the past two years, in the application of this plan as a part of the Taylor System of Management, in a works employing all told about one hundred and fifty men, and as a result this plant is not troubled in the slightest degree by the dearth of skilled mechanics.

9 Under this system of functional management, where formerly the apprentice had to depend upon one "overworked foreman" for his instruction, there are now several foremen, the most important of whom, so far as the matter of instructing the workman is concerned, are the gang boss, the speed boss, the inspector, and the shop dis-

ciplinarian. These men continually come in direct contact with the workman and each has a special function or duty to perform.

10 It is the duty of the gang boss to see that all preparations for each job is made in advance and to instruct the workman as to the best method for setting up his machine and setting and clamping the work. The speed boss decides all questions and has charge of all matters relating to the cutting speed, feeds, depths of cut, the kind and shape of tool to be used and the method of setting the tool, the number of tools to be used simultaneously, all matters connected with the proper use of soda water, and instructs the workman in the manipulation of his machine. The inspector is solely concerned with the quality of the work and instructs the workman in the degree of accuracy and finish required, while the shop disciplinarian, as his title implies, maintains the discipline of the shop.

11 Under such a form of shop management it has been found possible to take an absolutely green man, who has never worked in a machine shop, and make an efficient operator of him on a drill press, or turret lathe, in from three to eight weeks. From the drill presses the best of these men are promoted to milling machines and planers, and from the turret lathes to engine lathes, becoming proficient in each class of work in a remarkably short space of time, owing to the systematic and thorough instruction they receive from the various functional foremen. That these men are doing efficient work is fully demonstrated by the fact that in this shop we are turning out 100 per cent more work than was done before this system was installed, when every machine hand employed was supposed to be an all-around man.

12 One good example is a young man who started in about two years ago with no previous experience, and is now competent to run any machine in the shop and is at present running a lathe on which only work of a character requiring skill and accuracy is done. I mention this specific case because the man who formerly ran this lathe was looked upon as the finest workman in the shop, and at the time was the highest paid machinist in the employ of the firm, being considered indispensable by the superintendent in charge, when the functional system was started. This man, who was in reality a scientific loafer, objected to being told how to run his machine and as a consequence was allowed to leave, to be replaced by the young man first mentioned who not only turns out as good work as his predecessor, but about three times as much.

13 Another similar case is that of a young man who is now running a milling machine on which the most difficult and accurate work

is done. This young man when he first came was considered so stupid that we almost despaired of making anything of him.

14 From my experience thus far, I firmly believe that it is possible under the system of functional foremanship, to turn out in two years an all around mechanic who is in all respects a more efficient workman than is ordinarily turned out in four years under the old system and at practically all times during this period of training, to get practically the maximum efficiency from each man by reason of the constant and thorough nature of the instruction and help received at the hands of the various functional foremen, while the wages paid are so high as to attract mature men rather than immature and unsettled boys.

15 It has always seemed to me the height of unfairness to withhold the privilege of bettering their condition by learning a trade from deserving men, who through unfortunate circumstances over which they had no control, were unable to acquire one, and to restrict this privilege to boys alone, who seldom fully appreciate it.

16 This state of affairs is probably due to the fact that under the usual system of management, an apprentice is considered an expense item for a large portion of his time and is consequently paid low wages and expected to accept the experience and instruction he receives, in greater part as compensation for the period when his services are profitable to his employers.

17 Under the system I advocate, I think there would be very little to fear from this shortage of skilled labor which is at present such a burning question.

PROFESSOR LANZA The importance of providing skilled workmen, and the active interest that the manufacturer should take in the subject is so evident, that it needs no further argument. In order that such education may be properly provided, moreover, the manufacturers must realize that the matter cannot be left to the generosity of the multi-millionaires; their generosity alone will never accomplish it. The manufacturer has got to realize that it is necessary that he should bear his share of the expense and effort to accomplish it, even at the risk of losing the service of the men whom he has educated, by their going to other competing firms. Whether the program is to be carried out in the shop, or by means of schools not connected with the shop, there are certain things that will have to be attended to which are needed in consequence of the nature of the boy himself. The author of the paper speaks of the teacher looking after the development of the boys. I think in any large establish-

ment that a man will be needed to devote his entire time to looking after, not merely the schooling of the boys, but also their whole method of living. He should know where they board; how they live, and what are their habits. Then, there are other characteristics in the nature of the boy, which need to be carefully considered. A young boy is apt to look at any immediate raise in his pay as of undue importance; also he likes to aim high; he likes to imagine that he knows more than he does, and there is one great temptation in such schools, and that is to try to cover superficially a large amount of ground. Now, I think that the aim ought to be that everything should be done thoroughly, and what the boy has done shall be really accomplished.

MR. GEO. R. HENDERSON In connection with Mr. Porter's remarks, I would say, that about a year ago I noticed a large railroad shop, which was expected to employ about fifteen hundred or two thousand men, and at the very start the men had to walk for a mile or a mile and a half to the shop; the ground was torn up, there were no board walks down, and in rainy weather the consequences were that a great many men did not come to work because the facilities were too poor. I think that is one mistake we make; we ought always to look ahead to see that we will be able to get good men, and that they can be comfortably accommodated.

2 I would like to ask Mr. Alexander in regard to one of the points in his paper, and that is, how he manages to keep these men after he educates them so finely? I know of one young man who had been kept on a lathe 42 months out of 48, simply because he had developed into such a good man that the foreman kept him there, and when I introduced a system by which the young men were changed periodically, the foremen were very much disgusted, to have some of these young men removed and sent to some other department. I would like to know how Mr. Alexander keeps his men after he educates them. It seems to me that some of our competitors would pay them larger wages after we have educated them. I would like to know also, how you take a "chunker" and make a full-fledged machinist out of him without antagonizing the labor unions.

MR. L. D. BURLINGAME I can heartily endorse any plan that will help toward the adoption and development of the modern apprenticeship system. From my experience with such a system at the works of the Brown-Sharpe Manufacturing Company, I can see the importance

of a system for training men to develop skill. It has been for many years our plan to give such training. I am glad to see that not only individual manufacturers throughout the country are taking up this matter of the apprenticeship system, but that organizations such as the Manufacturers' Association, that are interested in the development of mechanical industries, are also taking action in a way that will help to spread and develop such a system. Of course, I understand that such plans as outlined by Mr. Alexander, when applied to a shop, must be adapted to the conditions in that shop. At the Brown & Sharpe works we consider it is best to have the boys mix in with the other men from the beginning; whether it be pattern makers, machinists, or draftsmen apprentices, we have them acquire their knowledge by such contact throughout the time of their apprenticeship. One point in Mr. Alexander's paper that I have heard criticised is that one boy is allowed to teach another from step to step. I consider this an advantage, as it trains the boy who is acting as instructor as well as the boy being instructed, and if this is done under a competent supervisor, he will see that a high standard is maintained, in which case it does not lower the standard.

2 Regarding what President Taylor said as to making of specialists—we feel that we are carrying out this plan to some extent where a boy is given training in the important departments of the works, such as the planing, the milling, the lathe, and the assembling departments, for a certain defined period in each, and where there will be instruction under an expert in that line of work.

3 I shall watch with great interest the plan being carried out by the General Electric Company. I feel that Mr. Alexander, has outlined very clearly the needs of our modern manufacturers for skilled labor and the means for developing such skill, and it seems to me he has shown in many ways exceptional skill in the plans suggested. I cannot too strongly urge that the apprentice system in its modern form should be pushed and developed throughout our manufactories in this country.

MR. C. F. MACGILL. Mr. Alexander's paper is a very important one. No greater problem is presented to manufacturers and superintendents today than that of supplying the required number of skilled workmen. The plan under discussion furnishes, it seems to me, the best solution of the problem. I visited the apprentices' department of the Lynn works and found that the instruction given was very thorough and systematic, and of such a nature that in a remarkably

short time the boys could be depended upon to do good commercial work.

2 In the primary training department work was done involving the simpler operations of drilling, boring, turning, balancing, etc., most of the work being on small cast iron pulleys. In the secondary or advanced training department, a really high grade of work was being done, turning armature shafts to a limit of one-half thousandth of an inch, making jigs and fixtures for use not only in the training departments, but throughout the works. I then went through some of the machine departments, where regular production work is done, and found the apprentices on that class of work for which it has been my aim for some years to train them.

3 I was particularly pleased with what I saw of their work in the steam turbine department at the River works. One apprentice in the fourth year of his course was running a ten foot vertical boring mill; others were working on large planers, milling machines, etc. It was very evident from the speeds and feeds used, that their training had been very thorough, and was producing good results. I cannot speak of the schools, as I was there in the summer, when they were not in session.

4 The impression seems to prevail among a number of engineers and educators that it is not necessary for an engineer or designer to be able to perform all of the operations involved in machine work, if he understands the underlying principles. I think this idea has done and will do a great deal of harm. The man who cannot do a given piece of work does not really understand how to do it. Mr. Alexander has started right, and the system carried out at Lynn is producing good results. Combined effort along similar lines by manufacturers and machinery builders in the United States will go a great way toward solving the question of providing the required number of skilled workmen.

MR. P. W. GATES It may not be generally known to the members of the Society, that the Manufacturers' Associations are moving in this direction. For instance, the National Founders' Association have erected a building and established a foundry school at the Winona Technical Institute near Indianapolis and I know there is under discussion by the National Metal Trades' Association, the use of a large building at the same place which they intend to remodel for a school for the machine shop and kindred trades in which said association is interested, the work in both cases to be taken up along practical lines. That seems to me to be the logical solution of the problem.

If such associations will take up the work there will be little difficulty in selecting the proper instructors out of the employees of some of its members and proper material to operate upon from their shops. I suggest this to Mr. Alexander, as anticipating his idea of trade schools.

2 I also want to say to Mr. Porter, regarding apprentices leaving shops as soon as they have finished their time that I have in mind an institution that turned out a good number of apprentices each year and which gave them their diploma and compelled them to leave. Their experience was that about seven out of ten would shortly return with sufficient additional wisdom to pay them compound interest on the investment.

3 I think Mr. Alexander's system can be carried further to good advantage; there should be two more grades of apprenticeship, one for the graduates of manual training schools with a shorter term and higher wages; another for graduates of technical schools with a still shorter term and higher wages. I have had a number of such graduates ask my advice about entering business and I have always told them that I thought their education at a dangerous point without being supplemented with shop practice to complete it and that then and not till then were they really entitled to have their diplomas signed and commence the post graduate course of their life work.

PROF. EDWARD ROBINSON It would seem that the plan of Mr. Alexander is one that could hardly meet all cases.

2 There are two parts to this plan that should be clearly distinguished. First, there is a general education; and second, a special training. In most modern apprenticeship systems, a fair general education is assumed before the young man enters upon his work. He is then given his special training in the particular industry in which he has elected to serve. Mr. Alexander, evidently finding it difficult to get young men with the proper preliminary education, essays to make up the deficiency by giving the boys a more or less general education previous to, and along with, their special training. This is certainly a very good thing and under the circumstances seems to bring about the desired results in the easiest possible way. The question arises in my own mind if it would not tend to a more logical and permanent solution of the problem, if manufacturing concerns should aid in encouraging and founding separate schools, which would give the proper preliminary education leading to the apprenticeship work? Such schools should be thoroughly educational, should give training in mathematics, elementary physics, mechanical drawing,

and manual training and have the avowed object of fitting the boy for apprenticeship work in the various neighboring industries.

3 The boy then should have some preferential treatment in the apprenticeship course, such as a shorter time to serve and more pay at the outset. Such schools would meet a decided lack in our present educational system, and if they could be established in various cities, it would not seem difficult, after they had proven their usefulness and efficiency, to have them become a part of the regular public school system. Such a school course followed by a good apprenticeship training, would give to a great many boys a far more effective and valuable education than any that is now open to them. For this reason it should command public confidence and support as soon as it has demonstrated its effectiveness and worth.

MR. JOHN KNICKERBACKER The paper on "A Plan to Provide for a Supply of Skilled Workmen" is one that could be profitably read by every employer of skilled labor in the country, as the employers might find some way to introduce in their work a plan that would eventually add to the efficiency of their force and give the boys a better chance.

2 There is a scarcity of good workmen and a lack of general interest on the part of employers to encourage boys to learn mechanical trades. To overcome these conditions it is necessary to first arouse the interest of the employer in the training of young men, and the interest of the young men will follow, for the desire for advancement is not yet killed by the preacher of class hatred. There is a moral and patriotic duty to train the young men in our employ, but this cannot be accomplished without some well directed comprehensive method, and methods will be found if we try to discover them.

3 It seems to me that so far as it lies in the power of this Society, it should endeavor to create a strong interest in this subject of training the apprentices by encouraging the submitting each year of papers on this question. This is a matter that is receiving the attention of some of the large manufacturers' associations, notably the National Founders Association. They have within a year encouraged the establishing of a model foundry school at Indianapolis under the charge of the Winona Assembly, and it is the desire of many of the members of that Association that that school shall become a model for the foundries of the country to follow in the training of their apprentices.

4 It is not an easy task to train these young men, and in order to obtain satisfactory results it is necessary to make careful selections,

and what has been done by the General Electric Company shows that this process of elimination has been carried out, for of the 462 boys at one time or another in the course at Lynn, 171 are still on the apprentice shop course, 37 are serving the trial period, and 29 have graduated. These 237 men and boys are about 51 per cent of the total number of boys received. It is to be earnestly hoped that the generous example of the General Electric Company will be followed, and that this Society will do its utmost to help along the good work.

PROFESSOR A. L. WILLISTON There are several points which I would like to emphasize in this most admirable paper of Mr. Alexander, in which he describes what is being done in the Lynn works of the General Electric Company to train and educate for efficient service in later years the young men and boys who are entering their employment.

2 I will not enlarge upon the need that exists at the present time for skilled workmen or the still greater need for intelligent and competent foremen and assistant superintendents to plan and direct their work; nor will I dwell upon the fact that the progress which thus far has been made in this direction, here and there where modern systems of supervised apprenticeship have been introduced, is so slight as to amount to practically nothing when compared with the immensity of the whole problem of providing trained and competent workmen for the present and future requirements of the rapidly growing mechanical industries of this country. These facts are too well understood and too self-evident to need either demonstration or argument before this Society.

3 The first point, however, in Mr. Alexander's paper to which I wish to call attention, is his inclination to hold the manufacturers themselves largely responsible for the small amount of progress that has been made in this direction. He blames them, and I think justly, for not having found more effective means of joining forces with the educators. In this, the initiative properly belongs with them. They are the only ones who know with accuracy the requirements, or the type of individuals who will be likely to succeed in their work. Without their aid and coöperation the professional educator will be able to make but little headway. They, too, are the ones who have the greatest financial interest in the problem. In many instances the future success or failure of their business may depend on its proper solution, and a large part, or even the whole, of their invested capital may be at stake. Buildings and the best equipment are worth but

little when not manned by an organization that can cause them to make money.

4 President Eliot said of Harvard University, when questioned a few years ago regarding the cost of duplicating it in a western state, "The bricks and mortar probably could be duplicated for about ten million dollars, but two hundred and fifty years of experience come high," and similarly one of our past Presidents has said in comment, after passing through one of the large and recently established industrial plants visited a short time ago by the Society, "*Money will purchase a magnificent equipment, but it takes years to perfect an organization.*" I repeat these remarks in order to emphasize the fact, as Mr. Alexander suggests in his paper, that an efficient body of trained subordinates is the most important asset in many a prosperous business; and also to emphasize the length of time which it takes to build up such an organization if it is low, or if it has been allowed to run down.

5 If these facts were realized in their full significance, I believe that the manufacturers of this country would feel that it was worth while for them to coöperate in some effective way for their own future interests, and would appreciate—in the popular parlance of the day—that it was "squarely up to them" to take some effective steps to insure a sufficient supply of high grade subordinates for their future need.

6 The second point that I wish to refer to is, that Mr. Alexander's plan aims to provide men unlike those produced under the older apprenticeship system with the fixed ideas and equally fixed prejudices, but instead, a new type of skilled mechanics who will be progressive, resourceful, and, so far as possible, ambitious to coöperate in the development of the company. His hope is to train men of intelligence, who can reason from cause to effect, who can perform one process with some relation to the process which is to follow; who can readily adapt themselves to new conditions, and who are receptive and eager for new ideas: men who believe, not with the old line mechanic, that their method is always the best, but who have faith that always there is a better method possible that is worth their striving for, which they can reach if they are open minded and have patience to persevere. This is the type of man that large organizations must rely upon for their future strength.

7 Those who have received as their early training—as is usually the case in the regular apprenticeship—nothing but a chance to imitate the handwork and the methods of others will not, except

in very rare instances, be fitted to rise into the many important subordinate positions found in a modern manufacturing plant.

8 The means which Mr. Alexander has adopted by which he hopes to accomplish these results are worth the most careful consideration. He frankly acknowledges that neither the old method of apprenticeship nor anything that approaches it will produce the desired result. The special foreman whose duty it is to look after the interests of the apprentices may be of some service, but they alone cannot accomplish what is wanted. Much more is required.

9 In the system in vogue in Lynn, they have practically turned all the old ideas regarding the training of apprentices completely upside down. Instead of giving to the boys, as is usually the case, any old thing to keep them busy, making them run errands and do all sorts of monotonous and uninteresting tasks which require neither intelligence nor skill, they have given them the best that their shops afford.

10 They have given them the best and most intelligent foremen in the factory to act as instructors, and have chosen for the type of work which they should do such things as the rebuilding of old tools, so as to insure higher degrees of accuracy; the making of jigs, the special tools and fixtures, tool making, and even practical tool designing. In other words, they have chosen for them the best work and the best conditions in their entire works.

11 These things are evidently wisely planned, with the idea of cultivating intelligence and reasoning power; of broadening the view of methods of manufacture, and lastly, but most important of all, of stimulating ambition.

12 It is not necessary for me to compare the influence of this treatment with that of the experience which surrounds many and many an apprentice boy in an average modern manufacturing plant, where he encounters rebuff after rebuff which tend only to dampen his enthusiasm and crush his ambition. We cannot wonder that the boy who starts on his life work, under such conditons, at fifteen or sixteen years of age, full of hope and determination, finds by the time he is but little past twenty, at the end of the period when he should have been growing and developing most rapidly that—unless indeed he has remarkable courage and pluck—he has less ambition, less receptivity for new ideas, and less willingness to coöperate for the general good of his company, than at the time he first entered their employ.

13 There are other points in this paper which should be taken up and discussed. Some of these are: the desirability of having the man

who knows most about the boy's intellectual attainment determine his pay; the value of the certificate given; the effect of such a system on the attitude of all the employees toward their work and toward the company; the possibilities of the evening courses that Mr. Alexander has suggested, and the possible coöperation between the public schools and school shop.

14 To summarize the paper, let me say that it is a most practical demonstration of the fact that, as a cold business proposition, it pays for a company to go almost to any expense in order to do everything in its power to stimulate the ambition of the boys it takes into its employ; and that any money spent to help them to believe more thoroughly in themselves, to have more confidence in their own intelligence and powers, and to have more faith in their capacity for future development will, like the bread that was cast upon the waters, be returned after many days. We have heard things like this before without the figures to substantiate the statements. It is therefore most gratifying to know that in this instance the General Electric Company finds, as a matter of actual bookkeeping, that the balance here is all on the profit side of the ledger.

15 In conclusion, I wish to thank Mr. Alexander for bringing this matter before the Society and to congratulate him on the splendid work that is being done under his direction at Lynn.

PROF. C. R. RICHARDS I am very glad to have an opportunity of discussing the paper of my friend Mr. Alexander, because in the first place it seems to me such an important contribution to the problem of providing skilled workmen in mechanical industries.

2 Mr. Higgins' paper of seven years ago developed a remarkable and interesting discussion. In Mr. Alexander's paper there may be perhaps less to discuss, but if this is true it is only because it represents seven additional years of study and progress and deals largely with concrete results rather than a suggested plan.

3 The significant heart and center of the plan here described, it seems to me, is to be found in the separate equipment and provision for instruction independent of the commercial practice of the shop.

4 It has come in my way during the past few years to examine either directly or through the reports of others the workings of over thirty apprenticeship systems in various manufacturing establishments. The best of these systems places the apprentice under the care of a foreman who is responsible for his instruction during the entire course of the apprenticeship, and although it is very true that good work is being accomplished by this method and some very com-

petent men being turned out, it seems to [illegible] plan described by Mr. Alexander is a very important step in advance.

5 The inherent weakness of any scheme of training workmen in the regular conduct of a shop lies in the fact that a shop organization is established for production and not for instruction and consequently any attempt at instruction not only entails a certain economic loss, but, from the nature of the case, can never reach a maximum of efficiency.

6 For these reasons the provision of a separate equipment, as described in this plan, for purposes of instruction and of separate instructors whose sole business it is to teach the learner, makes for results that are practically impossible under any supervising system.

7 It may be said that the possibility of such a plan is limited to the establishments of large manufacturing corporations; and this may be true, but in the first place it should be noted that there are a great many large corporate manufacturing establishments in the field today requiring highly skilled workmen, and there are liable to be more. How far it is practicable to extend this system of training to smaller establishments it is hard to say and this can be determined only by experiment.

8 When Mr. Alexander passes from the definite account of what has been done in a commercial establishment to what may be done by a school independent of any commercial establishment we are on much less certain ground.

9 Here we cut loose for certain tremendous advantages presented by the shop school and face some extremely difficult and as yet unsolved problems. These are almost wholly of an economic character: first is the problem on the side of the learner who is put to the expense of losing a steady though small income, and second, the problem of maintenance of the school.

10 In the shop school the product contributes to the total production of the establishment, and for this reason it is possible to defray part or whole of the expenses of maintenance and to pay good apprentice wages to the learners.

11 Mr. Alexander suggests that the school can provide for the design and manufacture of an easily salable article and that able business management may overcome certain difficulties. If able business management can solve these economic difficulties and make a school shop pay for its maintenance and return a wage to the learner it will have gone far to solve the whole problem of industrial training. As yet, however, the practicability of such a proposition remains to be demonstrated.

12 The demonstrated fact that is so clearly brought out in the paper is that a remarkably efficient system for training skilled workmen has been developed in a commercial establishment through making provision for instructions separate from the regular shop organization.

THE AUTHOR The discussion, in which several gentlemen have kindly participated, has brought out many interesting points that are worthy of consideration, and has indicated that my plan of training young men for all-around skilled artisans has not been quite fully understood as relating to the methods employed in the apprentice department at the Lynn works of the General Electric Company.

2 It is claimed that separation of the apprentices from the journeymen will produce disadvantageous conditions for the boys. This segregation, however, as I have explained, takes place only during the first two years of the apprentice course, when the boys are grouped in a training room where they receive systematic instruction in the trade on commercial work, the remaining two years being spent among the journeymen in the different departments of the factory.

3 This plan is justified by the consideration that, inasmuch as the attitude of many of our workmen of today toward work is not conducive to the best interests of the boys, apprentices should not be surrounded during the initiatory period by workmen, but should be kept under the sole influence of two or three picked instructors. These instructors endeavor to teach knowledge and skill as well as to build up the character of the boys, instilling into them honesty of purpose and a sense of their obligation to perform their work with the greatest speed and accuracy, regardless of wages or any other similar consideration.

4 When such attitude toward work has been sufficiently developed in the apprentices as will fortify them against adverse influence in the shop, they are then assigned to different factory departments where they work side by side and in competition with the journeymen for the remaining years of the apprentice course.

5 The training room, however, has another function to fulfill which is of great importance and which has evidently been misunderstood by one of the speakers in the discussion. It is true that only three instructors are engaged in teaching skill to about one hundred apprentices in the training room this being made possible by utilizing most of the apprentices themselves for assistant instructors. It must be borne in mind that the regular teachers instruct all boys, but after an apprentice has once been shown by the instructor how to perform

an operation, he can safely be put under [illegible]nce of an older apprentice for further practice of the particular operation, with the regular teacher looking after him and his boy instructor as the occasion requires. Thus the apprentice training room is run economically and the apprentices are taught to teach. No further argument is needed to demonstrate the efficacy of this plan than the fact that it has proved eminently successful during the five years of application at the Lynn works of the General Electric Company.

6 The functional foremen system, which has been advocated in the discussion, will not bring about these results; its chief value lies in the possibility of turning unskilled workmen into skilled specialists. The same end may be reached through a course of practical evening instruction, such as I have outlined in the latter part of my paper.

7 It has been pointed out properly that the wages paid to our apprentices are considerably higher than those usually paid in other factories. I cannot, however, agree with the plea which has been made for a still further increase of 50 or 100 per cent in the wage schedule in order to attract to the apprentice course young men of from 20 to 25 years of age rather than boys of 16. While we do not close the door of apprenticeship to desirable young men of mature age, I doubt that, except in individual cases, they will prove of greater worth both during the apprenticeship and afterwards, than the boys of 16 who come fresh from the school. Having usually spent their time between the ages of 16 and 20 in aimless work, these young men are not generally amenable to systematic instruction; often they have gotten into the rut of daily routine of unskilled work and are not sufficiently ambitious to pull out of it. Had they been taken in hand at the age of 16 they would probably have entered a field of skill at that period and avoided the forming of bad habits which have accumulated during the years of floundering and must be corrected during the years of apprenticeship.

8 In the long run, he will prove to be a more efficient and desirable artisan who has been under systematic training from his sixteenth year, or from about the time when he left school, than he who begins to acquire skill at a later period of life. Furthermore, is it not our duty to take care of the boy of 16 or even 15, if he is obliged to leave school at that age, and start him on the right road? The healthy boy is able to engage in mechanical work even at that age, especially if the work is selected judicially. The contact with real industrial life will, furthermore, mature him much quicker than would be the case during the same period of time spent in the school.

9 After the apprentices have been at work for about six months, and not any sooner, are they obliged to attend classroom exercises. The purpose of this academic instruction, however, is not intended chiefly for the purpose of giving the boys a general education that they may not have received in the public schools; it is rather intended to correlate the practical work of the shop and the theory that underlies the work, in order to illumine the former by the latter, so that the boy may be able to apply in the work-shop, day by day, the knowledge which he gains in the classroom. Incidentally the classroom instruction endeavors to rectify some of the defects which are found in the educational equipment of the boys.

10 I admit that most of the classroom instruction and the early part of the practical training may be given to advantage in special industrial schools established as a part of the public school system, so that graduates from such schools may enter upon an advanced apprenticeship in the factory. Until such schools are established, manufacturers must take the responsibility of training their own recruits. The efforts of some manufacturers' associations in founding practical training courses for boys who desire to learn a trade must be heartily welcomed; private enterprise has usually provided the initiative which precedes marked advances in the public school system.

11 The problem of retaining the apprentices after graduation has been pertinently pointed out by several gentlemen. A reference to the statistics which I have given in my paper will show that, as far as our apprentices are concerned, more than 80 per cent of the graduates have remained in our employ. The problem, therefore, does not exist for us at present, although I realize fully that we may not always be able to maintain as large a percentage; in fact, our expectations right from the beginning have been that we may be able to retain ¾ of the graduated apprentices. After all, we must take a broad view of the question and content ourselves with having improved the personnel of American factories in general, if we cannot confine the improvement to our factory alone. In some instances the young journeymen will undoubtedly be benefited by what the Germans call "Die Wanderjahre," where the contact with new conditions will round them out and broaden their horizon. The chances are that many of those who have left the company will return to their alma mater better men for themselves and for the company.

12 We encourage all desirable graduates to remain in our factory by offering them good wages and good prospects. Depending upon the individual worth, we pay graduated apprentices from $2.50 to $3.00 per day, and advance them as the excellency of their work

warrants. Several of the gradu[illegible]ave al[illegible]y [illegible]n placed in positions of responsibility, two serving as assistant foremen. All apprentices know that it is our hope and intention to have most of our future foremen and assistant foremen recruited from the graduates. A strict and almost severe training during the four years of learning and a liberal policy toward those who have successfully finished their course will, in my estimation, prove to be the best policy.

13 As our industries develop more and more, the position of the industrial foreman will become more and more important. His equipment must be skill and knowledge; how great a part of the allotted time is to be devoted to the one or the other will depend very much on the educational preparation of the boy and on the nature of the trade that he wishes to learn. Whether the apprenticeship course is a "half-time school," or as I prefer to call it a "part-time school," matters not as long as skill and knowledge are taught in a correlated manner.

14 I am sure that the system in vogue at Lynn will undergo further developments; the key note, however, which we struck right at the beginning and to which we shall hold fast, is to stimulate the ambition of the apprentices at all times. It is for this reason that we have set no fixed schedule for the time allotted to the various operations in the practical work; each boy is required to perform the operation in an entirely satisfactory manner both as regards speed and accuracy, and as soon as he has accomplished these results he is allowed to proceed to the next operation. It is interesting to see at times a boy instructor of but six months' of service guiding an apprentice who has been on the course for nine months and more. Too often, as has been pointedly remarked by a gentleman, the ambition of the boy is stifled rather than stimulated under other forms of apprenticeship.

15 In conclusion, let me urge upon all manufacturers the necessity of giving serious thought and of applying a liberal policy to the training of the future skilled workers in their factories. Let them coöperate with the educators in an endeavor to make the educational system meet the industrial demands, but, in the meantime, let them not rest on their oars, but supplement their educational advice by the demonstration of educational activity.

No. 1124

THE FLOW OF FLUIDS IN A VENTURI TUBE

By EDGAR PARK COLEMAN, BUFFALO, NEW YORK
Member of the Society

1 Converging and diverging tubes and combinations of the same, with many of their properties, have been well known for many years. The diverging tube was investigated by Bernouilli in 1738, and by Venturi in 1791. The object of these investigations was to determine the coefficients of discharge for these tubes when used as nozzles for the discharge of water from a reservoir. In 1887 Herschel published the results of his experiments, showing that the Venturi tube is an accurate meter for measuring the quantity of liquid flowing through it.

2 While the use of the Venturi tube for the measurement of liquids is quite general, its application to the measurement of gases does not seem to be well known to, or at least practiced by, many engineers. That the Venturi tube is an instrument of convenience and precision when used for measuring the quantity of air or gas (and in some cases of steam) flowing through it, the writer will show by the results of experiments.

3 The volume of fluid passing any cross-section of a pipe or tube per unit of time is equal to the product of the area of the section and the velocity of the fluid. Since the velocity is not usually directly observable, it became necessary to determine the relations existing between areas, velocities, pressures, and densities, from which the velocity at the throat may be calculated when the other quantities are known.

4 About the middle of the eighteenth century, Bernouilli discovered the law, since known as Bernouilli's theorem, governing the steady flow of liquids in a pipe. This law is a statement of the fact that for any pipe of whatever varying cross-sectional area, through which the liquid has attained a steady flow; considering any point in the length of the pipe, the sum of pressure head, velocity head, fric-

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tion head lost up to that point, and height above datum, is equal to a constant. Stated mathematically, the law becomes:

$$P_1 + \frac{v_1^2}{2g} + F_1 + h_1 = P_2 + \frac{v_2^2}{2g} + F_2 + h_2 = \text{Constant} \qquad [1]$$

5 For short lengths and low velocities, the loss of head by friction becomes negligible, and if in addition we assume a horizontal pipe, or in the case of a non-horizontal pipe, if the difference in pressure between the two points be measured by means of a U column, the term "height above datum" disappears and the expression becomes,

$$P_1 + \frac{v_1^2}{2g} = P_2 + \frac{v_2^2}{2g} = \text{Constant} \qquad [2]$$

The velocity must vary inversely as the area; that is, $v_1 = \frac{A_2}{A_1} v_2$, and by substituting this value in equation [2], and solving for v_2, the formula for the Venturi water meter becomes:

$$v_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh} \qquad [3]$$

as proved by the experiments of Herschel; where A_1 and A_2 are the respective areas of up-stream and throat cross-sections in square feet, v_2 is the velocity at the throat in feet per second, and h is

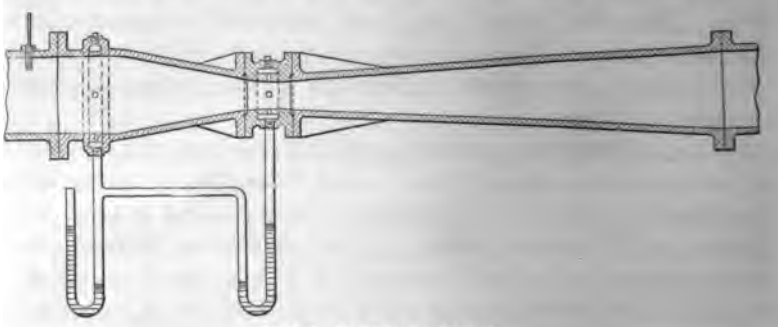


FIG. 1 VENTURI TUBE

the difference in pressure due to change of velocity, between the up-stream and throat sections, expressed in feet of the liquid. Herschel's experiments with water show this expression subject to a coefficient to correct for friction losses. This coefficient has an average value of 0.972, being greater for low and smaller for high throat velocities.

6 For measuring water it is desirable that the throat area be such that the throat velocity shall be between the limits of 15 and 35 feet per second. It frequently happens that the amount of water to be meas-

ured varies greatly from minute to minute. In such cases, greater accuracy is secured by taking the square root of h for each observation separately, and then averaging. We thus obtain the average square root of h which is desired, rather than the square root of the average h. It is also important to remember the correction for the water column, if a mercury U column, as is usual, is connected in differential between up-stream and throat. Thus if:

H = deflection of mercury column in inches;
h = pressure difference in feet of water;
13.59 = sp. g. of mercury;

$$\text{Then } h = \frac{(13.59\text{-}1)\ H}{12} \qquad [4]$$

7 In the preceding, it is of course assumed that the integrating register is not available, which if in use performs all of the above mentioned steps automatically.

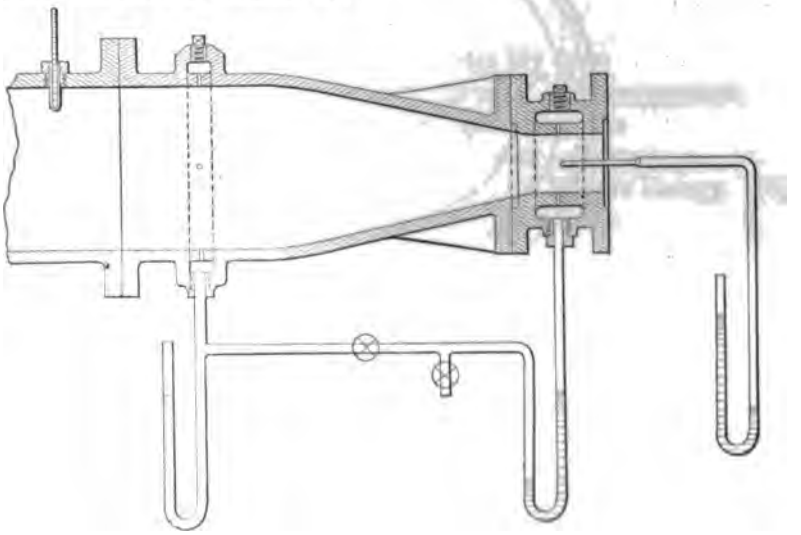


FIG. 2 CONVERGING NOZZLE

8 The flow of steam and air through nozzles and orifices has been investigated by Zeuner, Hirn, Peabody, Rateau, and others. The general formula governing the flow is ascribed to Wantzel and St. Venant in 1839, and is:

$$\frac{v^2}{2g} = \int_p^P V\,dp \qquad [5]$$

which can be integrated when the relations between volume and pressure are known.

9 Bernouilli's law, equation [1], governing the flow of liquids in a pipe evidently will not hold in the case of gases or vapors, where temperature and density are intimately related with change of pressure. Apparently, a general law governing the steady flow of any fluid in a pipe is:

10 Considering any point in the length of the pipe, the sum of potential energy, kinetic energy, and energy otherwise lost up to that point (all per unit mass of the fluid) is equal to a constant. This applies to any pipe of whatever varying cross-section, as in this case to a converging nozzle, or to a Venturi tube. Neglecting friction, radia-

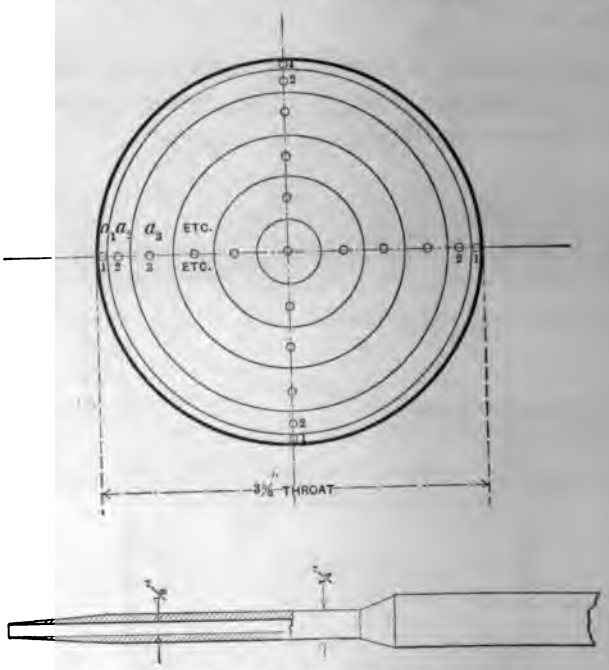


FIG. 3 THROAT CIRCLE AND PITOT TUBE

tion or other abstraction of heat or its equivalent, we may say that the total energy per unit mass of fluid is constant. Obviously this last will apply without material error within a limited range of lengths or velocities or both. It may be noticed in passing that when utilizing the Venturi tube as a meter we are concerned with the up-stream and throat parts only, which taken together form a converging nozzle, the sole function of the diverging down-stream part being to transform the major portion of the increased kinetic energy at the throat back again into pressure energy at the down-stream end, thus

reducing the pressure drop through the meter. The same formulæ, therefore, apply to Venturi tubes or to converging nozzles.

FLOW OF GAS IN A VENTURI TUBE

In the notation:
Subscript 1 refers to the up-stream section,
Subscript 2 refers to the throat section,
Subscript 3 refers to the down-stream section.
A = area in square feet;
P = pressure in pounds per sq. ft. absolute;
v = velocity in ft. per second;
C = volume of one pound of gas in cu. ft.;
Γ = density of gas = $\frac{1}{C}$
K = $\frac{\text{sp. h. at constant pressure}}{\text{sp. h. at constant volume.}}$

11 Referring to Fig. 1, gas flowing steadily from A_1 to A_2, will change in pressure, velocity, volume, density and temperature respectively from P_1 to P_2, v_1 to v_2, etc. Assuming the total energy per pound of gas as constant, we may write:
Decrement of Potential Energy = Increment of Kinetic Energy. [6]
Assuming adiabatic expansion,

$$P\,C^K = P_1\,C_1^K = P_2\,C_2^K \qquad [7]$$

12 The work diagram, *abcea*, Fig. 4, representing the change in pressure energy per pound of gas, while passing from the up-stream to the throat section, resembles in form the indicator card from a compressed air engine having zero clearance. The work performed by the gas through its expansion consists in changing its own velocity from v_1 to v_2, and is numerically equal to the area *abcea*. Bounded areas being understood:

$$abcea = abfoa + bcdfb - oecdo$$
$$abfoa = P_1\,C_1$$
$$oecdo = P_2\,C_2$$

$$bcdfb = \int_{C_1}^{C_2} P\,dc = P_1\,C_1^K \int_{C_1}^{C_2} \frac{dc}{C^K}$$
$$= \frac{P_1\,C_1}{1-K}\,C^{1-K}\Big]_{C_1}^{C_2} = \frac{P_1\,C_1 - P_2\,C_2}{K-1}$$

Hence,

$$abcea = P_1 C_1 + \frac{P_1 C_1 - P_2 C_2}{K-1} - P_2 C_2,$$

and since $P_2 C_2 = P_1 C_1 \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}$, and $C_1 = \frac{1}{r_1}$,

$$abcea = \frac{K}{K-1} \frac{P_1}{r_1} \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \quad [8]$$

13 The change in kinetic energy per pound of gas is numerically equal to $\frac{v_2^2 - v_1^2}{2g}$. Hence—

$$\frac{v_2^2 - v_1^2}{2g} = \frac{K}{K-1} \frac{P_1}{r_1} \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \quad [9]$$

Since $A_1 v_1 r_1 = A_2 v_2 r_2 = Q$,

$$v_1 = v_2 \frac{A_2}{A_1} \frac{r_2}{r_1} = v_2 \frac{A_2}{A_1} \left(\frac{P_2}{P_1}\right)^{\frac{1}{K}}$$

Substituting this value in equation [9] and solving for v_2, we get—

$$v_2 = \left(\frac{P_1}{r_1}\right)^{\frac{1}{2}} \left(\frac{2gK}{K-1}\right)^{\frac{1}{2}} \left\{ \frac{1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}}{1 - \left(\frac{A_2}{A_1}\right)^2 \left(\frac{P_2}{P_1}\right)^{\frac{2}{K}}} \right\}^{\frac{1}{2}} \quad [10]$$

The weight of gas in pounds per second is

$$Q = A_2 v_2 r_2 = A_2 v_2 r_1 \left(\frac{P_2}{P_1}\right)^{\frac{1}{K}}$$

$$= (P_1 r_1)^{\frac{1}{2}} A_2 \left(\frac{2gK}{K-1}\right)^{\frac{1}{2}} \left(\frac{P_2}{P_1}\right)^{\frac{1}{K}} \left\{ \frac{1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}}{1 - \left(\frac{A_2}{A_1}\right)^2 \left(\frac{P_2}{P_1}\right)^{\frac{2}{K}}} \right\}^{\frac{1}{2}} \quad [11]$$

$$= (P_1 r_1)^{\frac{1}{2}} M f\left(\frac{P_2}{P_1}\right) \quad [12]$$

Where M is the constant involving any given throat area and ratio of specific heats, and $f\left(\frac{P_2}{P_1}\right)$ is the quantity in equation [11] which

involves the ratios of pressures, areas and specific heats. It will be found convenient to plot $Mf\left(\frac{P_2}{P_1}\right)$ against the ratio of pressures, thus avoiding tedious calculations in practice. The locus of this quantity is shown in part in Fig. 5, for a tube involving a throat area of 0.07167 square feet, an area ratio of 0.13141, and a value of $K = 1.408$. In solving any concrete example then, knowing the values of P_1, $\frac{P_2}{P_1}$, and Γ_1 from observation, we obtain the corresponding value of $Mf\left(\frac{P_2}{P_1}\right)$ from the curve, substitute the necessary values in equation [12], and solve for Q. In a similar manner from equation [10] we obtain

$$v_2 = \left(\frac{P_1}{\Gamma_2}\right)^{\frac{1}{2}} M^1 f^1 \left(\frac{P_2}{P_1}\right) \qquad [13]$$

which is also plotted in Fig. 5. This curve is useful in determining the throat area required to measure a given amount of gas, under conditions given or assumed. For air (or gas of approximately the same

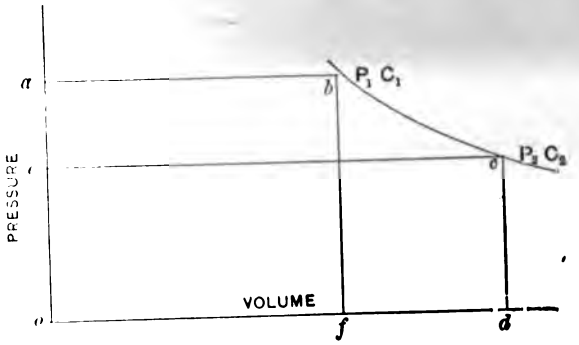


FIG. 4 WORK DIAGRAM

density), at or near a pressure of one atmosphere, desirable values of the ratio of P_2 to P_1 are between the limits of 0.95 to 0.995, corresponding to throat velocities of 100 to 300 feet per second. At higher pressure the throat velocity may be higher. In general the limiting value of the lower velocity depends on the least manometer reading which can be observed with sufficient accuracy, while the maximum allowable velocity will usually be determined by the allowable drop in pressure due to the meter

14 By making $v_1 = 0$ in equation [9], or $A_1 = \infty$ [illegible]quation [10], we obtain the expression for velocity under the condition of adiabatic flow through an orifice in a thin plate. Similarly, if $A_1 = \infty$ in equation [11], we have the expression for rate of discharge under the same conditions (an experimentally obtained coefficient of discharge being, of course, assumed).

15 When conducting some tests in 1903 of boilers using blast furnace gas for fuel, the writer was obliged to accept on faith the results from this method of measuring the gas. Later, in order to test its action with steam, a six-inch Venturi was placed in the steam line leading to the yards about a group of furnaces, boilers were isolated to supply the steam, the feed water was weighed, and observations were made at the meter by means of gages and mercury column. Sub-

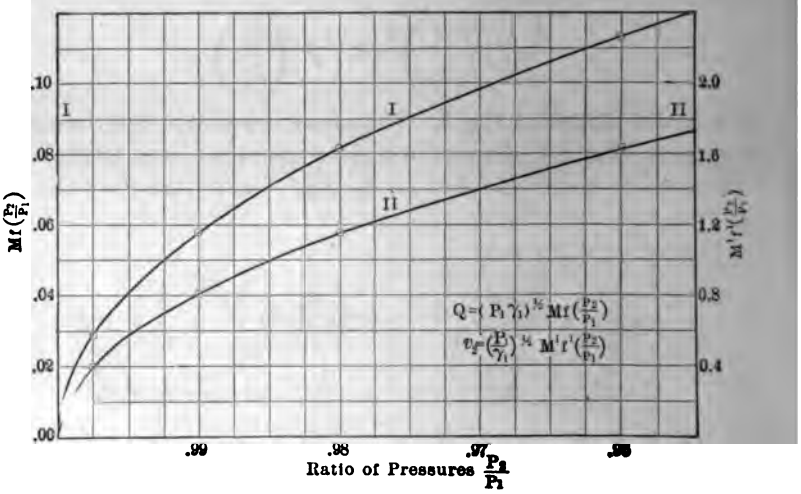


FIG. 5 COMPUTATION CURVES FOR 10" METER

sequently a six-inch and a ten-inch meter were connected to an air supply maintained at about nine ounces pressure above the atmosphere, and the results compared with those simultaneously obtained by inserting a Pitot tube in the throat of the meter. While the experiments were limited in number, and do not include a sufficient range of velocity, it is believed that they prove at least commercial accuracy.

16 In the experiments involving steam measurements, the steam was known to be about 99.5 per cent dry. The absolute pressure was about 110 pounds per square inch and the value of K was assumed to be 1.135. Two experiments were made, one at a throat velocity of 572 and one at 208 feet per second. The respective errors based on

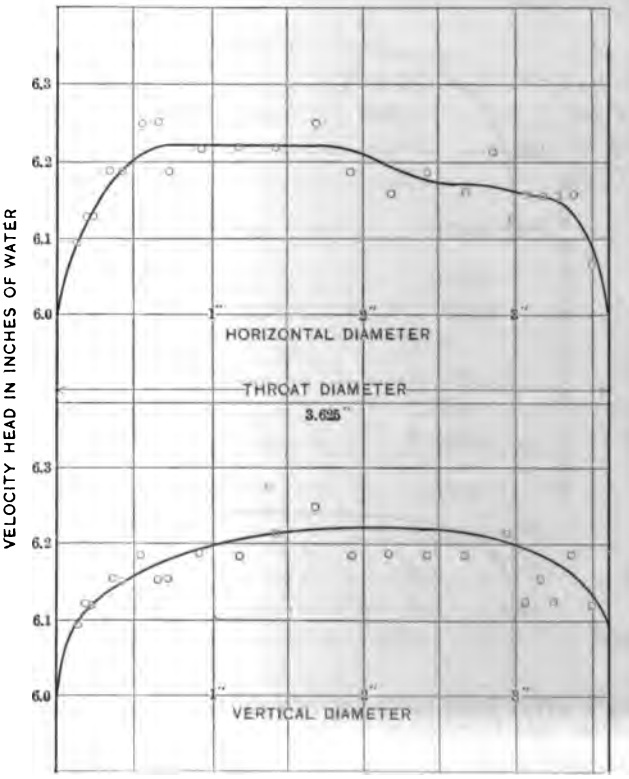


FIG. 6 PITOT TUBE READINGS IN THROAT OF 10" VENTURI TUBE

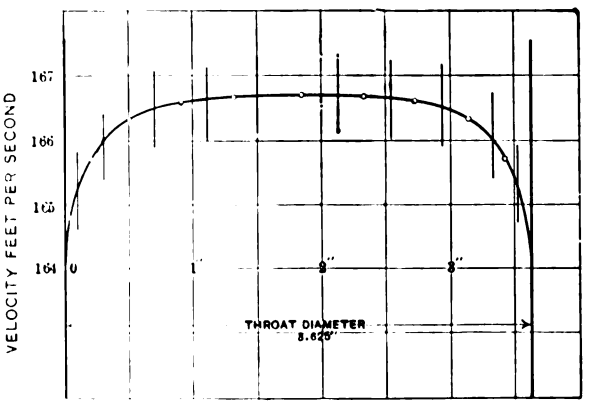


FIG. 7 AVERAGE VELOCITY DIAGRAM IN THROAT OF 10" VENTURI TUBE

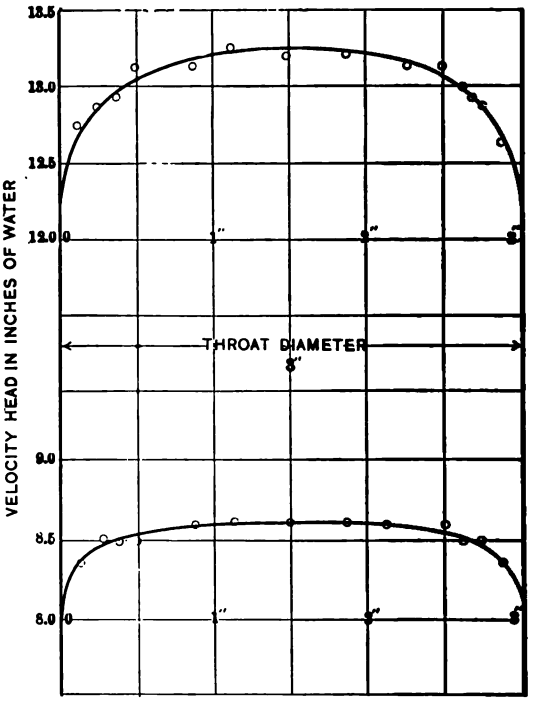


FIG. 8 PITOT TUBE READINGS IN THROAT OF 6" VENTURI TUBE

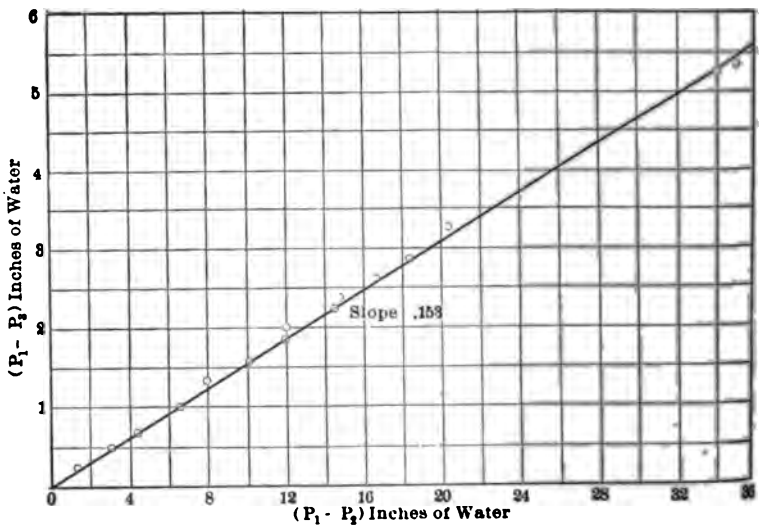


FIG. 9 PRESSURE LOSS IN 6" VENTURI TUBE

feed water weighed were + 0.056 and −0.84 per cent. The data from these tests are as follows:

Item	*Test No. 1*	*Test No. 2*
Date, 1904	Oct. 21	Oct. 22
P_1 lbs. per sq. ft.	15,666	15,934
P_2 lbs. per sq. ft.	14,470	15,775
$\frac{P_2}{P_1}$	.9236	.990
A_2 sq. ft.	.02182	.02182
A_1 sq. ft.	.19635	.19635
Barometer	28.73	29.23
K	1.135	1.135
Q lbs. per sec. by meter	2.851	1.1015
W lbs. per sec. by weight	2.8494	1.1108
$\frac{Q}{W}$	1.0006	.9916
γ_1 lbs. per cu. ft.	.2457	.2498
$P_1 - P_2$ lbs. per sq. in.	8.3	1.2
$P_1 - P_2$ lbs per. sq. in.	4.6	.4
v_2 ft. per sec.	572	208

17 While the above results indicate accuracy of the meter operating under the conditions mentioned, it is believed that with steam containing more than a small percentage of entrained moisture, that the results will be uncertain, owing to the change in the value of K accompanying the increased wetness of the steam. This belief was strengthened by the fact that a Venturi meter placed in the steam line which supplied two large simple duplex pumps, showed erratic results; that is to say, the steam apparently used per horse power hour varied greatly from day to day, even though the speed and condition of the pump remained the same. The steam was known to be very wet, and the arrangement of the piping made thorough drainage impossible. The attempt to measure the steam in this manner was therefore abandoned.

18 Referring to the experiments with air, the supply was taken through a six-inch pipe and discharged through the tube to the atmosphere. In the case of the six-inch meter, Pitot readings were taken along the vertical axis only, but when calibrating the ten-inch meter, Pitot readings were taken along both vertical and horizontal diameters of the throat circle, on account of a slight distortion of the stream lines due to ells in the up-stream piping.

19 Fig. 1 is a diagram of the ten-inch t... complete. Fig. 2 shows the same with the down-stream portion removed, the Pitot tube inserted into the throat, and the water columns connected. Fig. 3 shows a detail of the Pitot tube and the method used in obtaining the average velocity from the Pitometer readings, *i. e.*:

$$v_2 = \frac{\Sigma\ av}{\Sigma\ a}$$

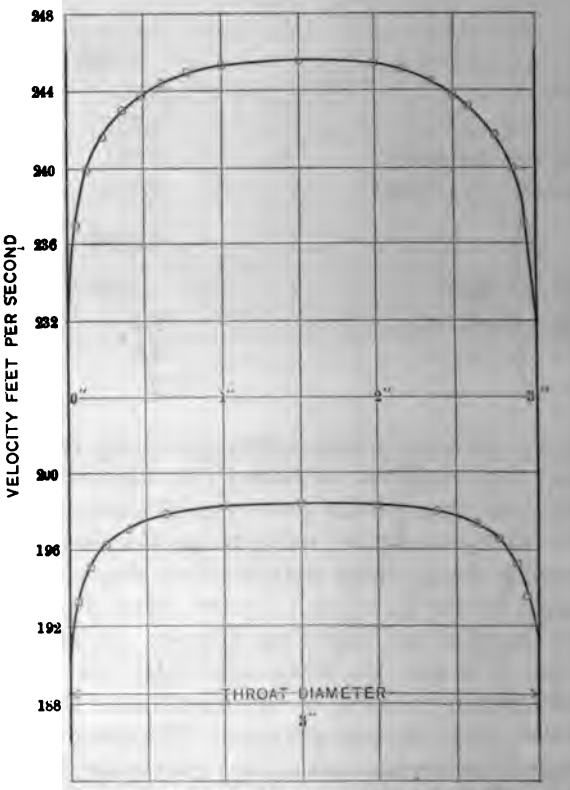


FIG. 10 AVERAGE VELOCITY DIAGRAM IN THROAT OF 6" VENTURI TUBE

Fig. 6 is a diagram of the velocity heads obtained by Pitot observations in the throat of the ten-inch tube when the pressure difference $(P_1 - P_2)$, was kept constant at six inches of water column. The velocity heads (1, 1, 1, 1, etc.) were averaged in fours, and from these averages was derived the average velocity diagram, Fig. 7, from which was computed the average velocity in the throat by the method mentioned above. The data and results for this test are as follows

Test number	3
Date, 1905	Nov. 9
Air temperature, degs. F.	60.5
Barometer, ins. Hg.	29.25
P_1 ins. of water	5.0625
P_2 ins. of water	−0.9375
$P_1 - P_2$ ins. of water	6.0
$\frac{P_2}{P_1}$	0.98511
A^2 sq. ft.	0.07167
A_1 sq. ft.	0.5454
K	1.408
γ_1 lbs. per cu. ft.	0.07552
γ_2 lbs. per cu. ft.	0.074715
Q lbs. per sec. by Venturi	0.88289
W lbs. per sec. by Pitometer	0.88986
v_2 ft. per sec. by Pitometer	166.2
Q/W	0.9922

) Other observations taken along one diameter only of the ten-meter gave results as follows:

est Number	v_2	Q/W
4	193.5	1.0017
5	193.5	.9916
6	191.6	.9970
Average	192.9	.9963

With the six-inch meter, Pitot observations were made along diameter of the throat circle. Two experiments were made, the and results from which are shown in the following table:

est Number	1	2
ate, 1905	June 27	June 27
ir temperature	75.0	75.0
arometer	29.47	29.47
ins. of water	9.0	6.0
ins. of water	−3.0	−2.0
$_1 - P_2$ ins. of water	12.0	8.0
^{2}	0.97012	0.98031
$_2$	0.04909	0.04909
$_1$	0.19636	0.19636
	1.408	1.408

r_1	0.... 4...	0.07418
r_2	0.07315	0.07314
Q	0.86745	0.70623
W	0.86962	0.70792
v_2	242.2	197.16
Q/W	0.9975	0.9976

22 The observed velocity heads and the velocity diagrams for these tests are shown in Fig. 8 and 10, respectively. Fig. 9 shows the pressure loss in the six-inch tube plotted against the increase of velocity head due to decrease in section. It is seen to be in this case 15.3 per cent of the said increase in velocity head. For a 16-inch tube having a 6¼ inch throat, it was found to be 23.8 per cent.

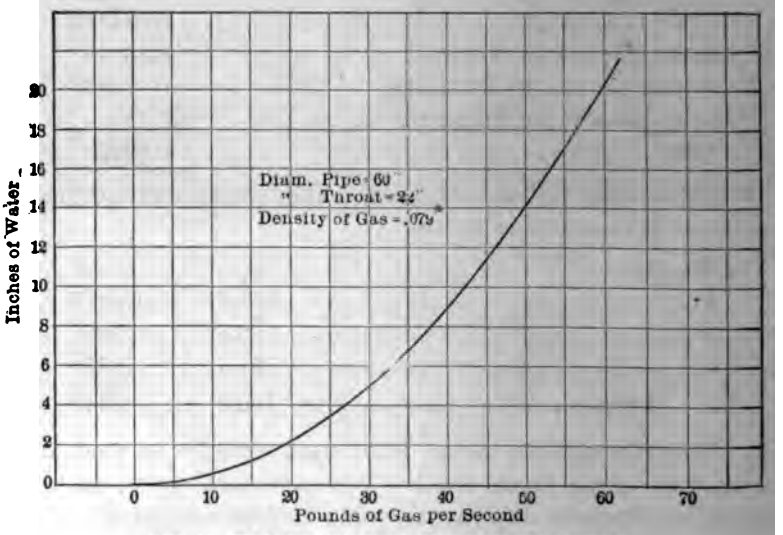


FIG. 11 COMPUTATION CURVE FOR 60" METER

23 Fig. 11 shows the quantity Q in pounds per second plotted against $P_1 - P_2$ in inches of water, for blast furnace gas of constant initial pressure, temperature and density, flowing through a five-foot meter, having a 22 inch throat. As the gas is usually held at a constant pressure above atmosphere, results based on this type of curve will be subject to errors due to variation of the barometer.

24 It is found that with blast furnace gas (and presumably with producer gas), a deposit adheres to the throat and other parts of the meter after continued use. This deposit if not removed affects the accuracy in two ways; first, by decreasing the area of the throat and, second, by closing or distorting the small holes leading to the

pressure chambers. This may be obviated in several more or less convenient ways.

25 The tests herein described (especially those with steam) do not cover a sufficient range of conditions to be conclusive in every way. While the method used for obtaining the throat pressures would be objectionable at very high velocities, the error here is negligible. With better facilities, and to determine completely the limitations of the Venturi as a measuring device, further experiments should be made covering a more complete range of conditions for both gases and vapors.

DISCUSSION

PROF. R. C. CARPENTER The paper giving the results of the investigations made by Mr. Coleman in relation to the use of the Venturi tube for measuring gases and fluids generally, is valuable for giving the coefficient for the use of the Venturi tube and also of proving its accuracy for measurements of this kind.

2 Mr. Coleman makes no claim as being the inventor of the method of using the Venturi tube which he describes, the properties of which have long been known by engineers, and which is in extensive use for the measurement of liquids; but he does show its substantial accuracy for the measurement of both air and steam. He also presents a simple method of connecting up the tube so as to obtain the pressures required for computing the results.

3 The results which Mr. Coleman presents indicate that the Venturi tube can be used with confidence for the purpose of determining the weight of steam flowing through a given pipe. The use of the tube in the way described is such as to eliminate the costly operation incident to measurement of feed water supplied to a boiler or of the water discharged from a condenser, and I believe should receive the endorsement of engineers generally for such purposes, as soon as coefficients applying to various conditions can be accurately worked out.

4 The St. John steam meter, which is used quite extensively in New York City for the measurement of steam supplied by the steam heating company, employs a Venturi tube of much the same character as that described by Mr. Coleman. This meter is provided with a recording apparatus and arranged to produce a diagram with difference of pressure as ordinates and time as abscissæ. The integration of the diagram multiplied by a proper constant gives the steam discharged.

5 With the Herschel Venturi meter used [illegible]easuring water, an integrating device is a part of the meter.

MR. SANFORD A. MOSS I would like to add to Mr. Coleman's remarks in praise of the use of a Venturi meter for measurement of gases. I have been using one for some time for the measurement of compressed air and have found it satisfactory in all respects. I have made calibrations of the instrument, similar to those made by Mr. Coleman, by comparison with discharge through a calibrated orifice, and have obtained practically the same results as those obtained by Mr. Coleman. That is to say, within errors of observation, the flow as measured by the Venturi meter agrees with the flow as measured by the orifice.

2 There is only one point of doubt in the whole matter and that is as regards the exact coefficient of discharge of the nozzle forming the initial portion of the Venturi meter. This coefficient possibly varies from 0.94 to 0.99. Of course, for usual commercial purposes, this difference is not significant and the coefficient may be guessed as 0.96 or 0.97. The Venturi meter will then be a perfectly satisfactory commercial instrument on which no further research or experiments are necessary. However, for more accurate work, it would be desirable to obtain more exact values of the coefficient under various circumstances. If such exact values were obtained, the Venturi meter would be an instrument of precision for both liquids and gases.

3 A set of mathematical formulæ for use of Venturi meters, equivalent to those of Mr. Coleman, but differing somewhat in form, is given in the "American Machinist," of September 20 and 27. The formulæ are there somewhat simplified by the fact that for the usual case the entrance velocity is practically negligible, and by use of an approximation first suggested by Boussinesq the results obtained are almost identical with those of the formidable exact formulæ.

4 I would like to inquire as to what coefficient of discharge Mr. Coleman used in reducing his experimental measurements of quantity by Venturi meter so as so compare with the measurements by other methods.

MR. CLEMENS HERSCHEL Venturi's experiments, published in 1797 were made with *expanding* ajutages only; not with compound tubes, such as I invented to be used as a water meter, in 1887, and then named the Venturi meter.

2 There is a tendency now to call such a tube a Venturi tube, and perhaps this serves me right for not having named the combination

the Herschel meter, when the bantling was in my hands to be named. But this is a small matter. See "Cassier's Magazine," March, 1899, for a history of the invention.

3 From the beginning it has been intended to use the instrument for metering any and all gases, no less than water; using the term gas in the general sense, which would include steam, compressed air, etc., but the valuable experiments and computations of the author of the paper are the first published on that class of work. Before the Boer war, negotiations were in progress to use the meter to measure the compressed air generated by one central station as it was distributed to several mining companies; but the negotiations were broken up by that war, and its only use for measuring gases, that I know of, is by the United Water Improvement Co. of Philadelphia, which practices the purification of water by the Vosmaer Ozone Process, by metering the ozonized air on its way to the standpipe which contains the water to be purified.

4 The author of the paper is disposed to rate the Venturi meter of gases by the use of Pitot tubes, and in the experiments here reviewed, the Pitot tube was used in the throat of a Venturi meter tube, apparently with the downstream cone of the meter first removed.

5 The question arises whether the discharge of the gas metered and the record of the pressure chamber of the Venturi meter would be exactly alike, when this downstream cone was on or off. But should a minute error lurk here, it seems to me that it would be more exact to test such a meter by volumetric measurement, by means of drawing from or into gas holders, and then test any Pitot tube system of metering the flow in pipes which may be selected, either by the same gas holders, or by the rated Venturi meter; provided any laborious and expensive use (in time, salaries, and money) of Pitot tubes would ever be wanted, after the Venturi meter for gases was once as well established as it is for metering water. It must always be remembered that rating any form of current or velocity meter does not establish the degree of accuracy of a form of volumetric metering, in which the current meter referred to, is to be or has been used. These two kinds of tests are always, or should always, be considered as quite distinct; even when perfect work, free from personal equation or error may be assumed on the part of any one, or successive, individual manipulators of the current meter in question.

6 A certificate of accuracy of any method of metering must depend, at some point in its genesis, on a strictly volumetric measurement; and following this, on a comparison between the computation made, and the absolute volume of the quantity metered. Any-

thing less than that will leave the user uncertain how closely theory followed by computation have come to represent the operation of the natural laws which produced the discharge volume which has been passing. Once rate the Venturi meter by gas holder test to meter gases, and it will replace, or can be used thereafter to test a Pitot tube or any other velocity meter method of metering such gases.

PROF. CHARLES E. LUCKE From the experience with the Venturi meter for measuring steam and gas, I am convinced that the device has considerable value, considerably more value than is ordinarily credited to it. In some recent tests made on some large gas engines at the Lackawanna Steel Company's plant, in Buffalo, for the De La Vergne Machine Co., a large Venturi meter was used as one of four methods for measuring gas. This meter is shown in Fig. 1. The tube had an actual upstream diameter of $15\frac{7}{8}$ inches, and the measurements at this point are denoted by the subscripts (1); the throat diameter was $6\frac{1}{4}$ inches and this point is denoted by the subscript (2). The downstream diameter was the same as the upstream and readings are denoted by the subscript (3);

Let V_2 = velocity of gas at the throat in feet per second;
p_2 = absolute pressure of gas, lbs. per sq. ft. at throat;
v_2 = cu. ft. per lb. of gas at throat;
A_2 = area of pipe in sq. ft. at throat;
K = 1.4, a constant.

Then the formula of M. de St. Venant applies

$$V_2^2 = \frac{2\,g\left(\frac{K}{K-1}\right)p_1\,v_1\left[1-\left(\frac{p_2}{p_1}\right)^{\frac{K-1}{K-}}\right]}{1-\left(\frac{A_2}{A_1}\right)^2\left(\frac{p_2}{p_1}\right)^{2/K}}$$

for this case

$$\left(\frac{A_2}{A_1}\right)^2 \cdot \left(\frac{6\frac{1}{4}}{15\frac{7}{8}}\right)^4 = .024025$$

This gas weighed 0.08227 pounds per cubic foot at standard atmospheric pressure of 33.947 feet of water, or 407.364 inches of water, or 29.922 inches of mercury. This must be corrected for a temperature of gas observed of 45 degrees F. and the barometer reported by the Weather Bureau of 29.249 inches of mercury or 398.2 inches of water.

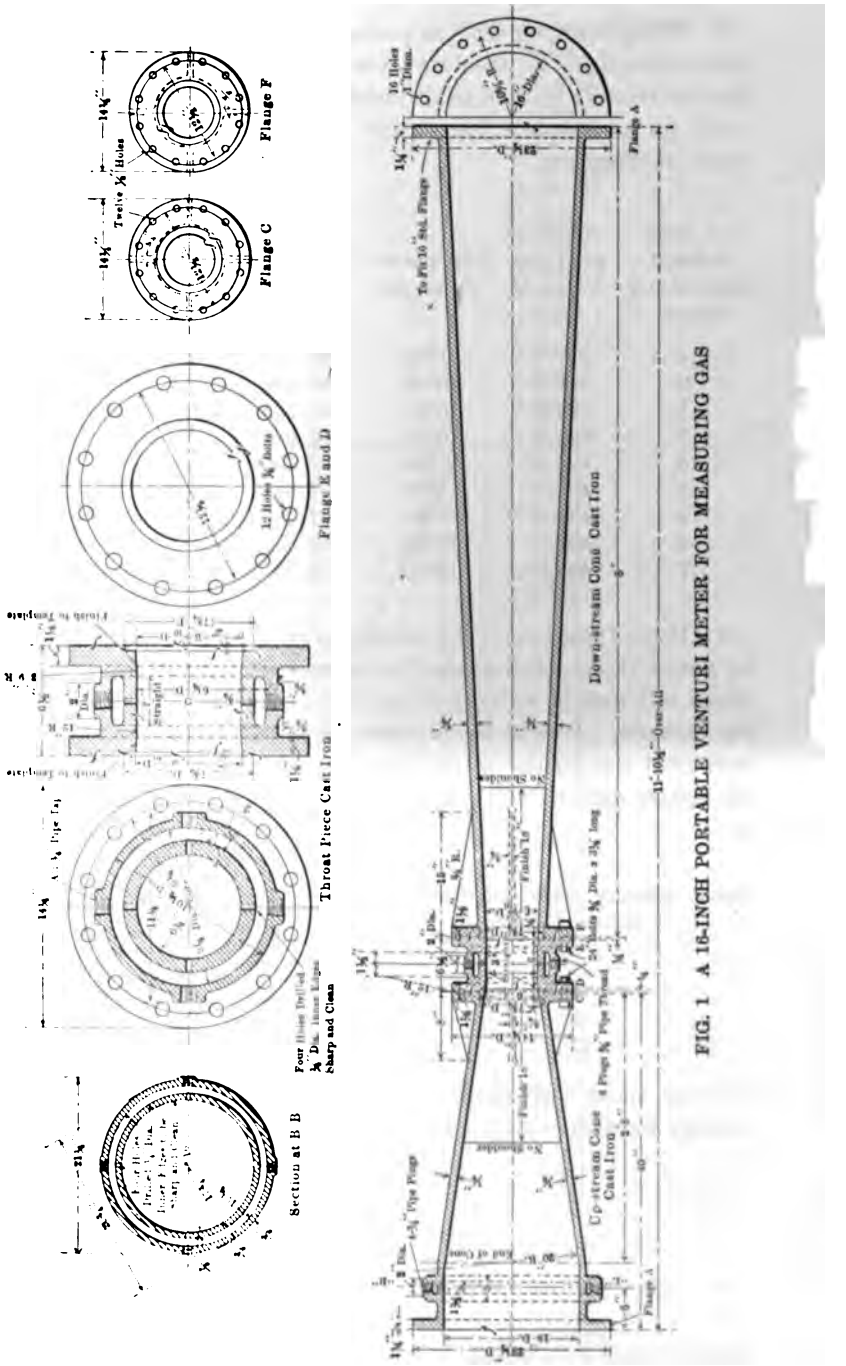


FIG. 1 A 16-INCH PORTABLE VENTURI METER FOR MEASURING GAS

2 This gives cubic feet per pound of gas = 0.07851 at the temperature observed and an absolute pressure of 398.2 inches of water. From this the velocity head of gas in inches of water or feet of gas can be computed for an absolute pressure of any number of inches above and below atmosphere.

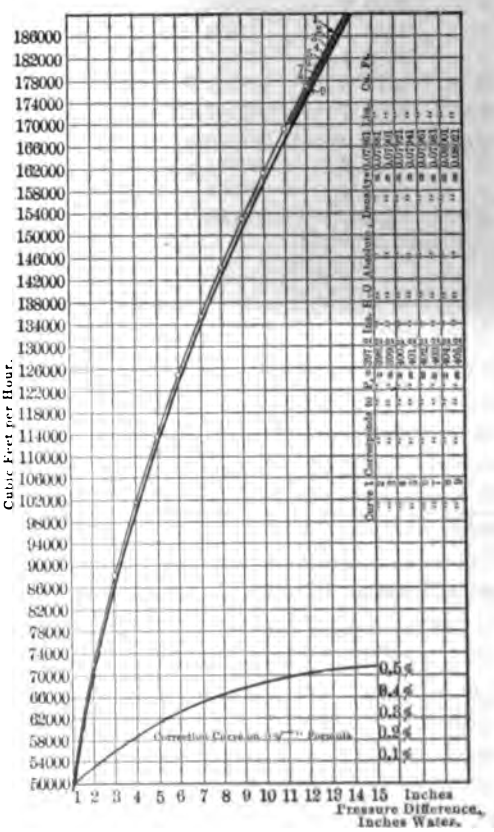
Gas press. inches of water above atmos.	Absolute gas press. inches of water	Lbs. per cu. ft. of gas	Lbs. per cu. ft. of water	Ratio wt. water / wt. gas	Feet of gas head per inch water velocity head
—1	397.2	.07861	62.335	793.220	66.102
0	398.2	.07881	62.335	791.207	65.934
1	399.2	.07901	62.335	789.204	65.768
2	400.2	.07921	62.335	787.211	65.601
3	401.2	.07941	62.335	785.229	65.436
4	402.2	.07961	62.335	783.256	65.272
5	403.2	.07981	62.335	781.293	65.108
6	404.2	.08001	62.335	779.340	64.945
7	405.2	.08021	62.335	777.400	64.783

3 Using these figures the velocity of gas at the throat was calculated for gas at these densities and for increase of velocity head due to the throat of 1 inch of water, 6 inches of water and 12 inches of water, by the formula. It was found that for increase in the velocity head increment due to throat contraction the flow varied very nearly as the square root of the increment and corrections were determined to be:

Throat velocity head increment in inches of water	Corrections to apply to velocity head increment method of computation
1	0.0000
6	0.0032
12	0.0051

Plotting these corrections on Fig. 2 gave the corrections for all velocity head increments due to the throat as follows:

Throat velocity head increment inches of water	Correction on square root method
1	0.000000
2	0.000304
3	0.000676
4	0.000911
5	0.001171
6	0.0032
7	0.0036
8	0.0040
9	0.0043
10	0.0046
11	0.0049
12	0.0051
13	0.0053



G 2 THEORETICAL CURVES OF VARIATION IN FLOW THROUGH THE VENTURI METER

COMPUTED IN CU. FT. PER HOUR WITH VARIATION IN PRESSURE DIFFERENCE, $p_1 - p_2$ IN INCHES H_2O FOR DIFFERENT DENSITIES OF THE GAS WHERE p_1 IS THE PRESSURE AT "UPSTREAM" PIPE, HAVING A DIAM. OF $15\frac{1}{4}$", AND p_2 IS THE PRESSURE AT "THROAT," HAVING A DIAM. OF $6\frac{1}{2}$"

The cubic feet of gas per hour from the thr ... head increment was computed by the formula for 1 inch, 6 inches, and 12 inches and by the proportionality to square root with the above correction for all other points. The three calculated results are given in the following table and the curves for all points are plotted in the curves on Fig. 2:

TABLE 1

Ins. water above atmos.	GAS PRESSURE: Ins. water absolute	GAS PRESSURE: Lbs. per sq. ft.	Lbs. per cu. ft. of gas	Increase in vel. head due to throat in ins. water	Vel. of gas at throat ft. per second	Cu. ft. of gas per hour
—1	397.2	2063.0	.07861	1.0	66.218	50,791
0	398.2	2068.2	.07881	1.0	66.127	50,732
1	399.2	2073.4	.07901	1.0	66.062	50,671
2	400.2	2078.6	.07921	1.0	65.939	50,516
3	401.2	2083.8	.07941	1.0	65.888	50,536
4	402.2	2089.0	.07961	1.0	65.782	04,565
5	403.2	2094.2	.07981	1.0	65.719	50,409
6	404.2	2099.4	.08001	1.0	65.598	50,312
7	405.2	2104.6	.08021	1.0	65.533	50,265
—1				6.0	162.717	124,807
0				6.0	162.494	124,635
1	Same	Same	Same	6.0	162.307	124,492
2				6.0	162.080	124,320
3	as	as	as	6.0	161.870	124,157
4				6.0	161.691	124,008
5	above	above	above	6.0	161.521	123,888
6				6.0	161.303	123,722
7				6.0	161.070	123,543
—1				12.0	230.709	176,957
0				12.0	230.315	176,655
1	Same	Same	Same	12.0	230.052	176,451
2				12.0	229.776	176,241
3	as	as	as	12.0	229.486	176,019
4				12.0	229.229	175,822
5	above	above	above	12.0	228.911	175,579
6				12.0	228.616	175,352
7				12.0	228.327	175,130

4 From these preliminary conclusions the data are ready for the test results. A characteristic set of possibilities is given in the following table:

TABLE 2

GAS

VENTURI METER

Run No. 1				Run No. 2				Run No. 3			
Time	P_1-P_2	P_2	P_1-P_2	Time	P_1-P_2	P_2	P_1-P_2	Time	P_1-P_2	P_2	P_1-P_2
	13.0	4.4	2.8		11.0	4.3	2.55	4.25	10.0	4.4	2.35
2.25	13.0	4.5	2.7	3.25	11.0	5.0		to	9.75	4.2	
to	12.5	3.5		to	11.2	4.8		4.50		4.6	
3.15		4.0		4.20		3.8		p.m.		3.8	
p.m.		4.9				4.5					
		4.6				2.6					
		5.0				2.7					

All pressures in inches of water

Run	P_1-P_2	P_2	P_1-P_2	P_1
1	12.9	4.55	2.75	7.30
2	11.04	4.06	2.55	6.61
3	9.88	4.25	2.35	6.60

In the above, P_1 is the gas pressure in inches of water above atmosphere, and $P_1 - P_2$ is the increase in velocity head due to the throat contraction measured also in inches of water. Applying these to the curves, the gas works out as follows:

Run	Cubic feet of gas per hour by Venturi
1	183,640
2	169,360
3	160,120

5 It was believed from these measurements that the Venturi meter was the most accurate method used, and it is freely recommended to all who have large quantities of gas to measure, even when the pressure on that gas fluctuates as violently as it may with a number of gas engines on the pipe, running in parallel. Since the time the previous reports of the tests were made, the Builders Iron Foundry made for me at my request a series of four Venturi meters in pairs of two, 1 and 2 inches in diameter with different throat ratios, for some determination of their value as devices for measuring steam. These meters have been set up in my laboratory and a number of tests made. In order that the meters may be checked for measuring steam, a Foster steam superheater is arranged in the steam supply to give any degree of superheat, and it is assumed that the steam is just dry when about one degree of superheat is observed. The results of these tests are not yet ready to be published, but it appears from what has been shown so far that it will be possible to use Venturi meters on steam lines. It may be that they will not be of great value to determine the weight of steam flowing in any line, but they certainly will give very valuable information on the per cent of the total steam generated in a header

and distributed from a header to each of the branches. If in a power plant the amount of steam flowing into the various branches be known as a proper fraction of the total, then it will be possible to charge the cost of operating whatever is supplied by that branch. In conclusion, I would like to say that I believe Venturi meters for steam work and gas work, especially in large sizes, are useful and their use should be encouraged.

PROF. A. L. WILLISTON There is one point regarding the Venturi tube which, thus far, has not been brought out in the discussion: that is, the difficulty of measuring with sufficient accuracy both large volumes and relatively small volumes of air flowing at different times through the same meter. In some experiments which I made in St. Louis a few years ago, this was forced on my attention. I had occasion to measure the flow of air, and used three different methods of measuring it; first, carefully calibrated anemometers; second, circular orifices of various diameters; and third, the Venturi tube. These three methods were used partly to get the best results under different conditions of flow, and partly as a check on one another. As a rule the result from all agreed closely.

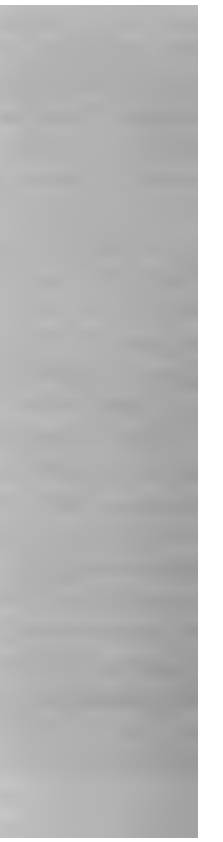
2 When the velocity of flow through the Venturi meter was approximately that for which it was designed, the results obtained were found to check with the results of other methods within less than one per cent, but when I attempted to measure small quantities of air with the same meter I found that the differences in pressure due to the small velocities obtained was extremely small. The fluctuations in pressure due to eddies and pulsations of air made the use of a very sensitive differential gage impractical; and without this the accurate determination of the flow was almost impossible.

3 With the circular orifices and with the anemometer this difficulty was not encountered, because it was such an extremely simple matter to change the size of the orifices and thus keep the velocity of flow approximately at any desired point at which the difference in pressure could be easily and accurately measured. The same thing, of course, could have been accomplished by using several Venturi tubes, but it would have required a number of meters of different sizes which could be readily substituted for one another as the volumes of the air to be determined changed. In many cases this would be impracticable, while with orifices different sizes can be substituted for one another in a slide properly prepared to receive them, at a moment's notice, and at slight trouble and expense. When the quantities of air, however, to be measured come within the range of a single

meter I have found the Venturi tube most satisfactory, and I feel that we are indebted to Mr. Coleman for bringing this subject to the attention of the Society.

THE AUTHOR With regard to a point brought out by Mr. Herschel, the instrument calibrated was in reality a converging nozzle, the down stream cone of the meter having been removed for greater convenience when inserting the Pitot tube into the throat. The formula, however, being based on constant energy per unit of fluid mass for steady flow in any pipe, is independent of all portions of the pipe, with the exception of the two sections considered, viz., upstream and throat. It would seem, therefore, that the absence of the down stream cone should not affect the coefficient of discharge at the velocities obtained in the experiments. The Venturi meter and the Pitot tube are rate meters, the Pitot tube presenting the greater opportunities for personal and other errors. The Pitot tube was used because of its well established coefficient, and trifling cost.

2 Replying to the question of Mr. Moss as to the coefficients of discharge, I wish to say that a coefficient of unity was used in all of the calculations. This gave, when measuring the air, two quantities in pounds per second for each experiment; *i.e.*, Q as calculated from Venturi observations, and W as calculated from Pitot tube observations. The average ratio of Q to W, as shown in the experiments with air, was 0.995. Hence, as far as these experiments show, if the coefficient of the Pitot tube is unity, the Venturi coefficient is 1.005; whereas, if the coefficient of the Venturi meter is unity, the Pitot coefficient is 0.995. This coefficient I believe to be constant for throat velocities of say 50 to 500 feet per second, and therein I consider the superiority of the Venturi meter over anemometers, standard orifices, etc., in which the coefficient of dischage is a function of the velocity, and must be determined by calibration.



No. 1125

BOILER AND SETTING

Improved Design for Use with Bituminous Coal

By A. BEMENT, CHICAGO, ILL.

Member of the Society

1 Fig. 1 shows an elevation and section of a modified design of boiler equipped with a chain grate stoker, although any other stoker machine would be applicable.

2 The principal objects to be secured in this design are:

a The attainment of a perfect and smokeless combustion;

b The full utilization of the boiler heating surface.

3 The first requirement is secured by the location of a tile furnace roof, which is supported by the boiler tubes of the lower row. The individual refractory tiles used in the formation of this roof are illustrated in detail in Fig. 2 and by a vertical cross-section, Fig. 3. The effect of the presence of this tile roof is to prevent the flow of unburned gases among the tube surfaces of the boiler, and to insure that they travel a considerable distance before the heating surface is reached, during which time these gases and the air present therewith may become sufficiently mixed together to insure entire combustion. The particular form of stoker shown, that of the chain grate, owing to the fact that the fuel is fed only on a horizontal line, and for which reason sudden and irregular charges of fuel cannot enter the fire, insures the apparatus to be entirely smokeless. It might be styled smokeproof, if this expression is permissible in this connection. When other styles of stoker machines are used under such roof, the attainment of complete combustion is dependent upon careful manipulation of the machine and fire, because the capacity of the tile roof furnace herewith illustrated is only sufficient to properly mix together the air and gases which flow from a chain grate fire. Therefore, in other forms of stokers, it is necessary for the uniformity in feed of coal and condition of fire to be equal to that secured with chain grates, for complete combustion to be effected. A considerable number of such tile roof furnaces are now in successful operation.

Presented at the New York Meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

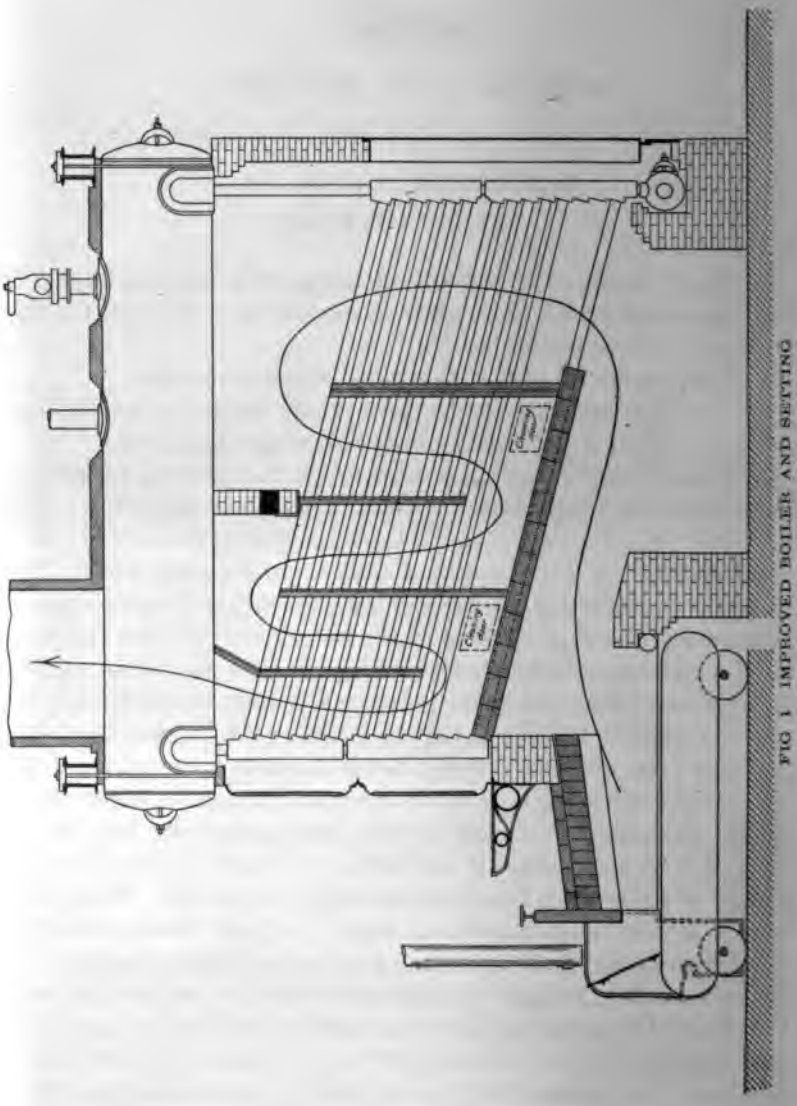


FIG 1 IMPROVED BOILER AND SETTING

4 To insure that all of the boiler surface shall be usefully employed the gases are led over the whole portion of it by means of passages of less area than are commonly used. It is the writer's observation that in many boilers various corners and other portions are not acted upon by hot gases, because the decreasing volume due to the gases becoming cooled is not equal to the capacity of the passage, for which reason in this design the additional baffles are employed. The decrease in size of these passages, however, is not in the same ratio as the reduction in volume of gas. Proportioning the passages according to the volume of the gases in the different parts of the boiler would have required at the inlet to the tube surface a space much larger, with the effect of very materially reducing the length of the tile roof. Therefore the compromise illustrated is adopted.

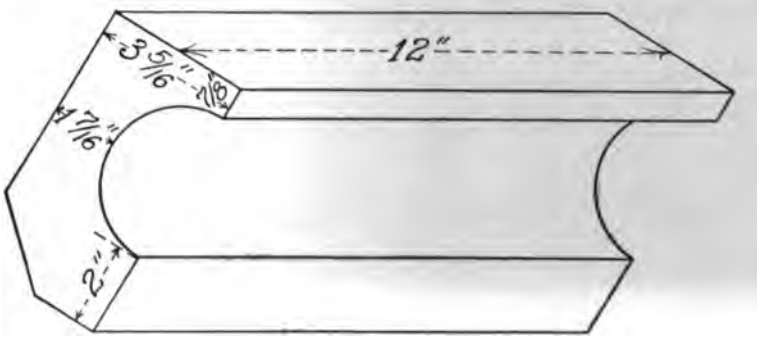


FIG. 2 REFRACTORY TILE FOR FURNACE ROOF

5 A space at the bottom of the boiler above the tile roof equal to that which would ordinarily be required by the second and third tier of tubes, is left vacant for the purpose of accumulating dust, which may be removed through cleaning doors in the side wall of the setting. The lower tubes supporting the tile roof are of 3.5 inches diameter, and of a heavier gage than the 4-inch tubes above. The smaller diameter is employed for the purpose of affording greater space for the necks of the tiles than is obtainable with the 4-inch tubes.

6 The contracted passages among the tube surfaces of this boiler necessarily produce a high resistance, and for this reason a strong draft is required, and this appears to be true of any boiler when arranged so that all of the heating surface is utilized. According to the author's present conclusions, a combination of forced and induced draft affords means for the production of the best obtainable combustion, particularly so with the chain grate stoker. The induced draft

may, of course, be obtained either with fan or chimney. The office of the forced draft is to move the gases as far as the furnace chamber, from which point they flow among the heating surfaces of the boiler to the chimney by means of the power of induced draft. Therefore, the influence of the forced draft extends from below the grate to the furnace chamber, while the power of the induced draft extends from the chimney among the heating surfaces to the point in the furnace, at which that of the forced draft ceases. Under such conditions the pressure of the gases in the furnace is the same as that of the atmosphere. This prevents a portion of the air leakage, which, under other conditions, would flow into the furnace chamber by way of openings at the stoker through the brick walls and elsewhere. By manipulating the intensity of the forced and induced draft, a balance of pressure may be obtained in the furnace chamber when varying amounts of coal are being burned. Therefore, this draft system operates not only to overcome the resistance due to the passage among the heating surfaces, but also insures complete combustion with a smaller air supply than would be the case with induced draft alone. This condition has been referred to as that of balanced draft. In this connection it may be well to call attention to the fact that forced draft cannot be depended upon to compel the flow of gases among the heating surfaces to any great extent, because when the pressure in the furnace chamber becomes greater than that of the atmosphere, the flames and fire will blow out through the doors, cracks, or other openings.

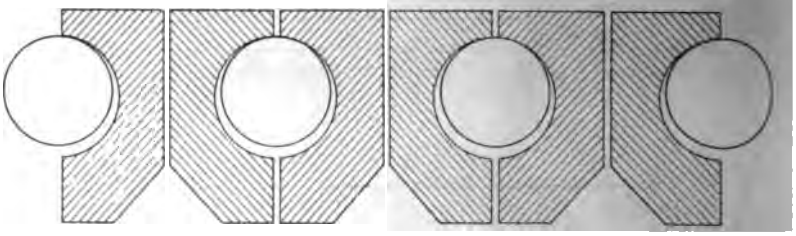


FIG. 3 SECTION SHOWING FURNACE ROOF

7 Figures are as yet not available, showing the exact effect of this particular arrangement of baffles, but results in a similar case of baffling[1] will serve to indicate that a high efficiency is attainable.

8 Data are, however, available, showing the effect due to the use of a balanced draft. The average of four simultaneous tests with a

[1] Trans. A. S. M. E., Vol. 26, p. 619, and Trans. A. S. M. E., Vol. 26, p. 418.

FIG. 4

CHIMNEY OF A. & CO. IN FOREGROUND; WATER TUBE BOILERS AND CHAIN GRATES WITHOUT TILE ROOF. CHIMNEY IN BACKGROUND THAT OF B. & CO.; WATER TUBE BOILERS AND MURPHY FURNACE

chain grate stoker located under a Babcock & Wilcox boiler gave the following average results:

	BOILER A NATURAL DRAFT	BOILER B FORCED DRAFT
Thickness of fire in inches	7.0	7.0
Per cent of coal used that would pass through ½ inch round screen	13.1	13.1
Total strength of draft in inches of water	0.389	0.380
Draft over fire in inches of water	0.389	0.00
Per cent CO_2 in furnace gases	5.03	7.32

Each of these tests covered a period of four hours and measurements were made at 15-minute intervals. Coal from exactly the same lot of fuel was used in each series of tests, so that a test for each kind of draft was made with a uniform lot of coal, thus avoiding the possibility of the fuel having an influence on the results. With each of these stokers there was a considerable opening at the end of the grate at the bridgewall, which, however, was the same in each series of tests. Otherwise a higher per cent of carbon dioxid would probably have been realized. The tests on each boiler were conducted at the same time, and alternating wheelbarrows of coal were supplied to the boilers.

9 So far as the author is aware, there are no features of the above apparatus which are patented.

APPENDIX

10 Since the above was prepared, it has been considered desirable to offer some examples to illustrate the performance of water tube boilers that are fitted with the tile furnace roof recommended in this paper, as compared with similar boilers without the tiles, from the standpoint of smoke, chain grate stokers being used in each case; also to illustrate the result secured by careful manipulation of Murphy stokers under the same type of water tube boiler. To this end the Fuel Engineering Company of Chicago, made an examination of certain plants in the same city, and the following quotation is from its report signed by Edward H. Taylor, Secretary, in which the owners of the two smoking chimneys in the photographic views are referred to as A. & Co. and B. & Co. to avoid undue publicity:

11 "A. & Co.'s plant (Fig. 4), located in the Stock Yards, has Aultman & Taylor boilers (Babcock & Wilcox type) served by chain grate stokers. There is no 'Dutch oven' or combustion chamber, the smoke going directly to the boiler. In the accompanying photograph showing two smoking chimneys, the one in the foreground is

that which serves these boilers and illustrates it at its normal appearance.

12 Chicago Edison Company: A photograph is shown below of the station of this company, located at Harrison street and the river. The main boiler plant is served by the four large chimneys. The boilers are of the Heine type and are equipped with chain grate stokers the same as the plant of A. & Co. The essential difference between the

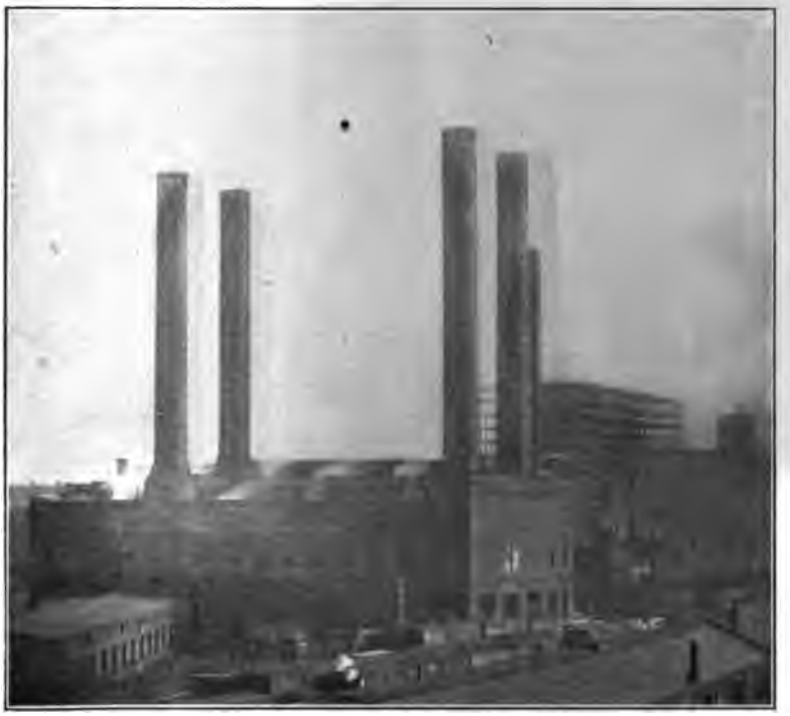


FIG. 5
PLANT OF CHICAGO EDISON CO. CHAIN GRATE STOKERS AND WATER TUBE BOILERS WITH TILE FURNACE ROOF

boilers of A. & Co. and those in this station, is that the Edison boilers are covered with sections of firebrick which extend from the front nearly to the back end of the boiler, so that the smoke gases pass along under these firebrick sections to the back end of the boiler instead of going immediately up to the front end as is the case with the boilers of A. & Co. The fifth chimney, or in other words, the small one shown in the view, is connected with other boilers which are seldom or

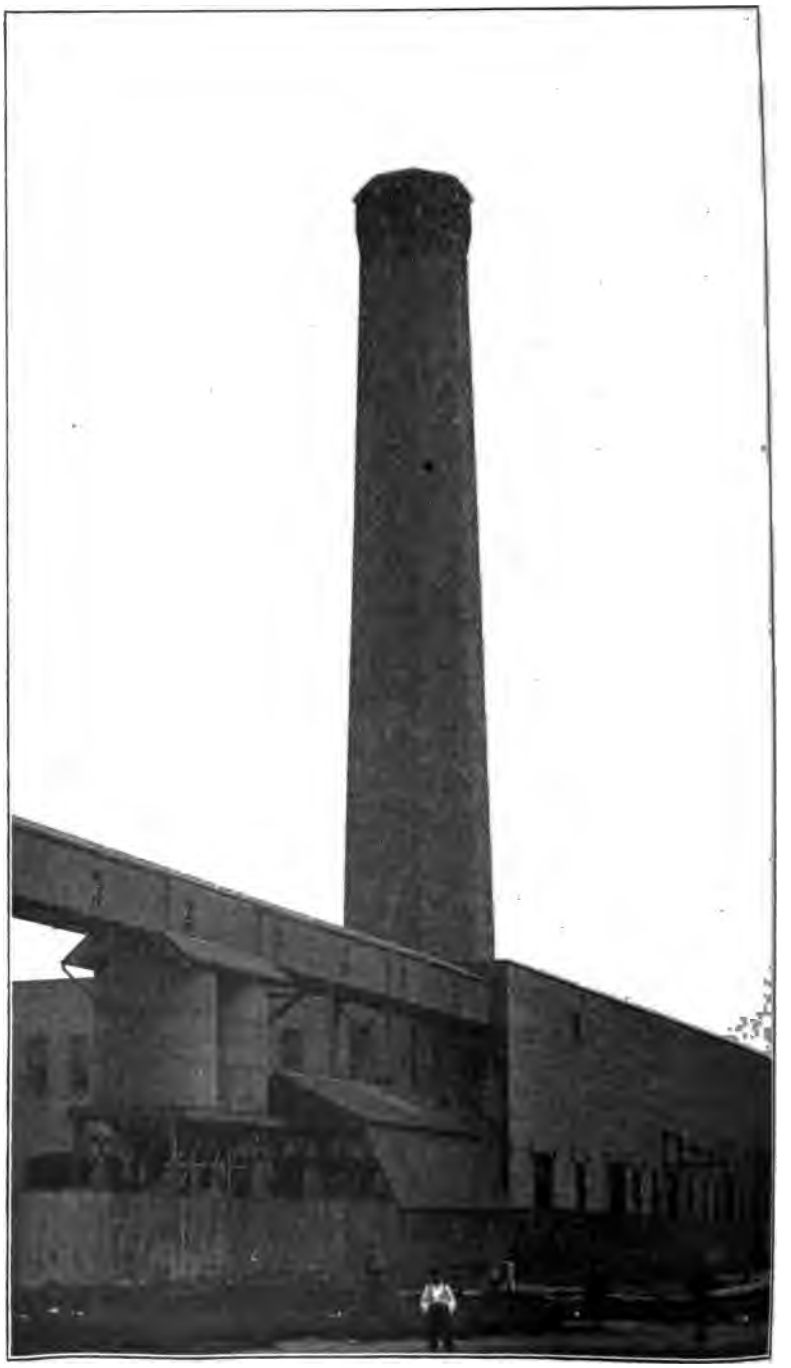


FIG 6

PLANT OF NORTHWESTERN ELEVATED RAILROAD COMPANY, OF CHICAGO. WATER TUBE BOILERS AND MURPHY FURNACES

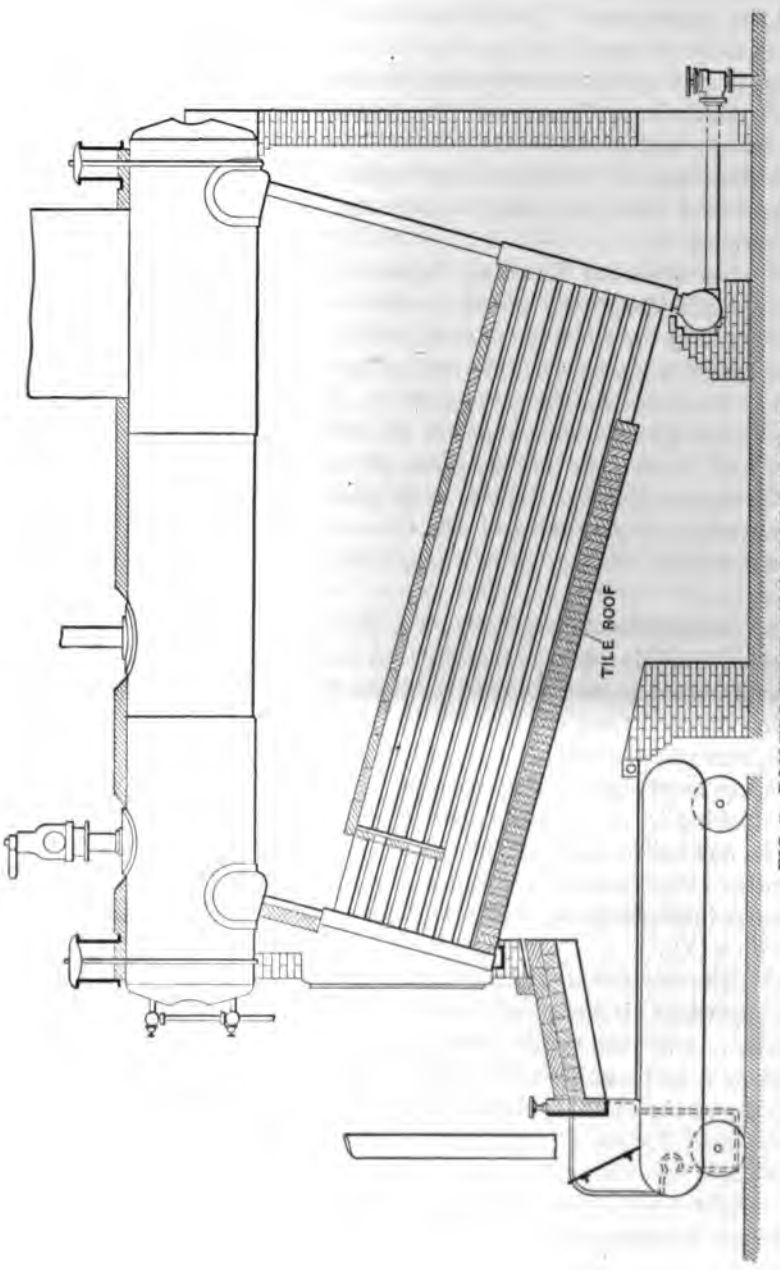


FIG. 7 BOILERS WITH TILE ROOF FURNACE
PLANT OF INTERNATIONAL HARVESTER COMPANY, CHICAGO

never in service. The above reference applies to the large chimneys and the appearance of these is indicated by this photograph, from which it would seem that the station was shut down; on the contrary, it is in operation every day, carrying a large load.

13 B. & Co.: One of the chimneys of this company is shown in the background of one of the photographs (Fig. 4). It is connected with Babcock & Wilcox boilers which are equipped with Murphy stokers and the photograph represents the chimney at its usual appearance.

14 Northwestern Elevated Railway: One of the accompanying photographs shows the power plant of the Northwestern Elevated Railway (Fig. 6), which is equipped with Babcock & Wilcox boilers and Murphy furnaces, or, in other words, the equipment is precisely like that in the above mentioned plant of B. & Co. The photograph represents the average appearance of the chimney.

15 Of these four plants, those of A. & Co., B. & Co. and the Northwestern Elevated Railway are of approximately 4000 boiler horse power each. The portion of the Chicago Edison Company's plant served by the four large chimneys, is 10,000 boiler horse-power capacity."

16 In addition to the above, Mr. W. L. Goddard, Engineer of the International Harvester Company has kindly furnished a sectional view of boilers in the McCormick Twine Mill, shown in Fig. 7, which he has changed from the usual vertical baffling to a single horizontal pass, and added a furnace roof, using a form of tile of his own design, differing from that of the author's. His letter which accompanied the drawing is quoted as follows:

"In our boiler arrangement (Fig. 7), the tiles have been on for 21 months. The furnaces are smokeless; gas samples taken every ten minutes for eight hours, with Orsat apparatus, gave an average of 13 per cent CO_2."

17 The effectiveness of the tile roof to prevent smoke is shown by Fig. 5, which is compared with the chimney in the foreground of Fig. 4, and further testified to by Mr. Goddard; and the result due to good and bad manipulation with a Murphy stoker is illustrated by Fig. 6 and the chimney in the background of Fig. 4.

DISCUSSION

PROF. L. P. BRECKENRIDGE The experience of the writer confirms that of Mr. Bement, namely that the tile roof furnace with a chain grate stoker appears to be a most satisfactory combination for the burning of many grades of western bituminous coals without smoke and with good economy. For years engineers and builders of boilers have been told that one of the fundamental requisites for smoke prevention was that the gases evolved from the fuel should not come in contact with the cold tubes or boiler plate until complete combustion had taken place. Nevertheless, little attempt seems to have been made by parties designing or building boilers or boiler furnaces to meet this requirement.

2 Builders of boilers have for years furnished plans for setting their boilers. They complacently say that they do not build stokers or furnaces but that any of the various kinds of stokers may be used successfully with their boiler. Parties building stokers or furnaces are equally ready to sell you their goods assuring you that they will give satisfaction under any of the standard types of boilers.

3 This method results disadvantageously to the purchaser. He does not know whom to blame for poor performance. It would seem that the time had come when a single manufacturer should sell the entire outfit consisting of boiler and furnace.

4 If this were done, we might then hope for better results for the purchaser. The alert builder who is soon ready to put on the market that combination of boiler and furnace which will burn bituminous coals without smoke and with an overall efficiency of even 75 per cent, both of which are entirely feasible, would be doing a great service to the purchaser of small or medium sized power plants, which must depend on bituminous coal for their fuel supply.

5 Is it not strange that the owners of power plant boilers are compelled to modify the standard settings as purchased in the market in order to meet the demands of the smoke ordinances or to increase their economy? The strenuous competition in most lines of design such as pumping engines, gas engines, turbines, generators, and electric motors has created appliances of high efficiency. The same thoughtful planning in the field of boilers, boiler settings, and furnaces would certainly be followed by the same satisfactory results.

6 At present there is an attempt to find some particular variety of coal of the right size which will burn in the furnaces now in use Should we not endeavor to decide what types of furnaces, settings,

and boilers may be depended on to burn the representative coals which are available.

7 A question which naturally presents itself in this connection is, what length of tile roof furnace is necessary for any kind of coal, or, how high above the grate should this roof be placed?

8 More than 460 trials of coals have been made under steam boilers at the Government Fuel Testing Plant at Saint Louis. In very many of these tests careful data have been taken of temperatures and gas analysis in the fuel bed over the fire, at the bridge wall and at the rear of the combustion chamber. It is evident from these tests that in the case of some fuels, combustion is complete one foot above the fuel bed while for other fuels the combustion is not completed at the rear of the combustion chamber.

9 In all these tests a tile roof furnace has been in use, as is usual with the Heine Boiler used in these trials. The writer hopes to soon present to the Society a review of this extensive series of trials. There are now available at the office of the Director of the United States Geological Survey, Washington, D. C. several publications relating to this work.

Mr. W. D. ENNIS This paper offers a remedy for a condition which is quite familiar to anyone who has operated water tube boilers of that type in which the path of the flue gases is parallel with the tubes. In such boilers, as usually set, if there are more than about eight rows of tubes running vertically, the gas passages are too large in proportion to the grate; and if we keep down to eight rows of tubes, we usually find that the boiler heating surface is too small to take up all of the heat that it should; so that we are apt to have to contend with either the short circuiting of the gases or deficient heating surface.

2 I have recently come across an exaggerated instance of this difficulty. The quotient of grate surface by gas passage area at successive points, beginning with the bridge wall, was 2.9, 6.2, 3.9, 4.8, 6.2, 3.5 and 11.8. With these boilers, having a ratio of heating surface to grate surface of 47 : 1, we can get as much as 13 per cent of CO_2 (although we cannot quite average that), but when burning upward of 18 pounds of coal (slack) per square foot of grate per hour we cannot hold the flue gases below 700 degrees. In this case we have insufficient heating surface, short circuiting, and badly related gas passage areas to contend with.

3 This question of capacity of boiler heating surface to handle high rates of combustion came up about two years ago in a western plant which I visited where California oil was the fuel. We had

some horizontal boilers built for burning wood. The boilers had four-inch tubes. We had to force them somewhat, and the flue gas temperature was high. We made six tests and found an average evaporation of 14.05, generating 3.76 pounds of steam per square foot of heating surface per hour. (The individual figures for evaporation ranged from 13.5 to 14.7 pounds.) Then we put retarders in the four-inch tubes; had the blacksmith twist them out of $\frac{1}{8} \times 4$ inch iron, and made five more tests. Our evaporation was from 14.9 to 16.0, with an average of 15.4, and a rate of steam generation of 3.96 pounds. As this gave us a pretty high efficiency, 80 per cent average, we checked the matter very carefully. As far as the forcing was concerned, we could not find that it made any difference. Our efficiency was just as high at 3.96 generation rate as it was at 3.0. This was a clear case of avoiding short circuiting through those big tubes.

4 We had a Babcock and Wilcox boiler in the plant, on which we ran two tests. Our highest evaporation, per pound of oil, was 13.7 pounds, the generation rate being 3.7 pounds. This made the Babcock and Wilcox boiler about 3 per cent less economical than the horizontal boilers without retarders, and 11 per cent less economical than the boilers with retarders, even disregarding the superior capacity for forcing, as in the case of the horizontal boilers. These results were fully confirmed by observations covering a year's actual operation. I understand that later on a considerable improvement was made by using tile wall retarders in the Babcock and Wilcox setting.

PROF. WILLIAM KENT Mr. Bement's proposed setting shown in Fig. 1 is a long step in the direction of smokeless combustion and of maximum absorption of heat by the heating surface of the boiler. The regular feeding of coal by the automatic stoker and the long travel of the gases under a fire brick roof are two most important features tending to give smokeless combustion, and boilers set in this manner can no doubt be driven without smoke when the thickness of the fire and the force of the draft are so adjusted as to provide enough air at all times to burn the volatile gases.

2 One trouble with nearly all furnaces designed for the suppression of smoke is that they do not make any provision for increased air supply at times when the boiler is driven beyond its normal rate, or rather when the furnace is driven beyond the rate at which no smoke will escape from the chimney. If the boiler is running at its normal rate, the volatile gases being completely burned, and then an extra demand for steam makes it necessary to drive the furnace faster, coal must be fed at a faster rate and

the thickness of the bed of coal is thereby increased. This thick
ening of the bed increases the resistance to the passage of air throug
it, and if the draft is not correspondingly increased, or if there
no provision made for introducing air into the furnace above th
coal, the air supply is diminished instead of being increased as
should be. I would therefore add to Mr. Bement's design some pr
vision for an adjustable supply of air which could be admitte
whenever the rate of feeding coal is increased to such a degree
to cause the production of smoke. Probably the best place
introduce this air is through the bridge wall and through openin
which carry the currents of air in opposite directions to the curren
of gas, so as thereby to make a thorough mixture. The air inl
should have an adjustable damper so that the additional air su
ply could be shut off when the boiler was being driven at a mode
ate rate.

3 I suggest that it would be well for Mr. Bement to make son
experiments with this setting to determine the maximum rate
which the boiler could be driven with Illinois coals without smok
both with and without the admission of excess air above the grat
Chemical analyses of gases should also be made, and there shou
be an attempt to adjust the rate of feeding of coal to the air supp
so that the CO_2 in the gases would approximate 14 per cent.
will probably be found difficult to get as high a percentage of C
as this with rapid driving and smokelessness all at the same tim
but a great deal of useful information could be gained from suc
tests, and we can especially learn from them something about th
relation to each other of a high percentage of CO_2 (which mea
economy), rate of driving, and smokelessness.

4 In regard to what Mr. Bement calls balanced draft, he say
that "it insures complete combustion with a smaller air supp
than would be the case with induced draft alone." He does n
give any reason for this conclusion and I am unable to find a
reason for it. The examples he gives show 5 per cent CO_2 in th
furnace gases with natural draft and 7.32 with forced draft. Bo
of these figures are far below what they should be for good economy
Suppose that we have three boilers all exactly alike except that o
is provided with forced draft, one with induced draft, and one wi
balanced draft. Let the total draft pressure necessary to burn th
coal at a normal rate of driving be 0.3 inch, and at 50 per cent abo
the normal rate 0.6 inch; and suppose that the resistance to flo
of gases through the fire is twice the resistance to flow through th
boiler tubes. We then would have the following figures for th

draft pressure at the bottom of the chimney, in the furnace, and in the ash pit, for the six different cases considered:

	Normal Rate of Driving,			Rapid Driving,		
	Forced	Induced	Balanced	Forced	Induced	Balanced
Chimney	−.3	0	−.1	−.6	0	−.2
Furnace	−.2	+.1	0	−.4	+.2	0
Ash Pit	0	+.3	+.2	0	+.6	+.4

5 If in the case of rapid driving the coal bed is thickened so that the gases of combustion have the same analysis as when the boiler is driven at normal rate with thinner bed of coal, I can see no reason why the same percentage of CO_2 in the gases might not be obtained in all of the six cases. The mere fact that in two of these cases the draft pressure is zero in the furnace does not, it seems to me, have any necessary influence in changing the constitution of the gases or in enabling complete combustion to be made with a smaller air supply than would be the case with induced draft alone.

6 The fact that greatly different pressures of draft may give the same constitution of escaping gas is clearly shown in the report of a test of the Babcock and Wilcox boiler for the United States Steamship "Cincinnati," quoted in my book on Steam Boiler Economy, p. 397. In seven tests, the rate of driving of the boiler ranged from 5.18 up to 13.67 pounds of water per square foot of heating surface per hour. The average per cent of CO_2 in the gases varied only between 11.8 to 14.5. The percentage of CO_2 varied only from 0.2 to 1.5 and the percentage of oxygen only from 4.2 to 6.9. pounds of dry gas per pound of combustible varied only from 16.8 to 20.6. The efficiency was remarkably high in all the tests, considering the very high rate of driving, ranging from 77.9 down to 64.5, the latter at the extreme rate of driving, of 13.67 pounds per square foot of heating surface per hour. It is not easy to see how this economy could have been improved by any system of balanced draft.

MR. W. L. ABBOTT In the territory which receives the greater part of its fuel from the coal fields of Illinois and Indiana a number of engineers are investigating the subject of boiler and furnace design, with a view to developing a type of apparatus better adapted to the long flame, high ash coals of that territory than the standard types of apparatus now on the market—something whose commercial efficiency will be above the 50 or 60 per cent, now obtainable, and which at the same time will relieve the owner from the

ever increasing persecutions of the [illegible]oke [illegible]. These investigations all point to three requirements essential for an ideal boiler plant using the grade of fuel above described, viz:

a A water tube boiler provided with an automatic stoker, which will gradually and continuously introduce fresh fuel at one end of the furnace and discharge the refuse from the other end.

b A tile roof above the furnace, extending well back of the fuel bed, which will compel the gases distilled from the fresh fuel to travel over the hot fire and back into a combustion chamber before permitting it to enter among the boiler tubes.

c An arrangement of baffles which will cause the gases to flow through every portion of the gas space of the boiler.

2 Every standard make of water tube boiler on the market possesses one or more of these qualifications, but none of them, so far as I am aware, possesses all of them. The advantages to be obtained by combining some of the best features of the different standard types of boilers into one design are manifest to those who have experimented with a boiler so modified, and yet when manufacturers are requested to furnish boilers so designed, each one objects to embodying in his own type some feature which he has not heretofore used, but which has proved to be one of the main advantages of boilers constructed by another maker. This conservatism exists in the selling departments, rather than in the engineering departments, and boiler makers are now being forced to listen to the demands for a special boiler design to meet the requirements of the users of cheaper grades of fuel, and I have no doubt that within a year or two they will all be glad to offer boilers designed substantially like the one which Mr. Bement describes.

MR. ALBERT A. CARY In the simplest setting of a Babcock & Wilcox type of boiler, where the grates are placed immediately below the first pass of the tubes, we have about as poor a furnace construction for the use of bituminous coal as could be designed.

2 It is generally understood that the combustion of bituminous coal is a two stage process:

a the driving out of the gases occluded in the coal by heat; and

b the burning of the solid combustible matter left behind, which latter combustion occurs on grates.

3 The first step of this process is a distillation of volatile gases from the coal. We next find these gases rising into the combustion

chamber above where they are consumed more or less rapidly, according to the temperature existing there, or else extinguished and not burned if this temperature is below their critical temperature of ignition.

4 As combustible gases also require more or less time (especially if diluted with non-combustible gases) they should not be rushed, even through a very highly heated chamber at too high a rate of speed to allow them time to ignite and burn to completion before coming in contact with the comparatively cold boiler parts.

5 The presented surface of the tubes is seldom more than a few degrees hotter than the water they contain, so that in a boiler carrying a steam pressure of 150 pounds, we cannot look for a tube temperature of much over 365 degrees, while the temperature of the unconsumed furnace gases should not fall below 1800 degrees.

6 With the simplest form of setting in a Babcock & Wilcox type of boiler, we find the volatile gases leaving the fire bed and rushing upward into a bank of practically cold tubes.

7 With anthracite coal containing very little volatile matter, we find this form of setting very desirable and with semi-bituminous coals, carrying less than 20 per cent of volatile matter, we find good results obtained, but the grate must be removed to a greater distance below the tubes than when anthracite is used. Baffle bricks between the tubes to retard the velocity of the gases are also found desirable, but when we go farther west and find coals running from 30 per cent to 50 per cent in volatile matter, which shows that from $\frac{1}{3}$ to $\frac{1}{2}$ of the total weight of the coal must be burned in the combustion chamber, we find nothing but low furnace efficiency resulting from the use of such a furnace, and we find the progressive manufacturers of this type of boiler suggesting a different type of furnace to their customers to meet this changed fuel condition.

8 With the use of the coal last described, running high in volatile matter, we find in the simplest form of setting, adopted by the Heine type of boiler an excellent form of furnace, one which discharges the volatile gases from the coal upward against a more or less incandescent firebrick roof, which is constantly radiating heat and thus assisting in the maintenance of the high temperature necessary for the rapid combustion of the volatile gases, and be it understood that the more rapid the rate of combustion, the higher the resulting temperature will be. In this form of furnace, with fuel running high in volatile matter, or distilling off volatile matter rapidly, a greater height between the top of the fuel bed and the firebrick roof should be provided than

with a fuel carrying less volatile matter, or one distilling off its volatile matter slowly.

9 Further in this design of setting we find a comparatively long run of gases from the furnace to the point where they enter the bank of comparatively cool boiler tubes, which design introduces the element of time necessary for the complete combustion of diluted combustible gases.

10 At the moment any fuel, whether solid or gaseous, completes its combustion, the resulting gases should be brought without delay into contact with the surfaces they are to heat, as a rapid cooling effect, due to radiation, follows cold air infiltration through settings, etc.

11 For this reason, this latter type of setting is not so well adapted for anthracite coal or coke fuel as the first described setting, owing to the fact that the combustion of such fuel, in a properly designed furnace, is almost entirely completed upon the grate bars.

12 From these well proven theories, we see that Mr. Bement has, in the form of furnace he offers, introduced the Heine type of furnace to the Babcock & Wilcox type of boiler, which will be successful, as a furnace, to the extent I have just outlined. If one were inclined to criticism, he might object to the sudden enlargement of the furnace at the inner end of the fire arch. This enlargement tends to cause a rarefication of the gases by their sudden expansion to fill the larger space found at this position.

13 Experience has taught that a condensation in the volume of gases brings their combustible portions into closer contact with the oxygen and facilitates the combination of these two essentials to combustion, which action produces the higher temperatures so essential to successful furnace operation.

14 With the chain grate stoker, which depends upon the coking method of firing, the distillation of the volatile gases is supposed to occur in the front part of the furnace (near the point of coal introduction).

15 At the rear of this grate, near the point of discharge, nothing is supposed to exist but ash, while between these two extreme positions, burning coke (resulting from the gas expelled coal) should be found.

16 Through the more or less porous coke bed and at the position of ash discharge, the greater part of the cool ash pit air passes and enters the furnace and combustion chamber.

17 One may say, this added volume to the furnace gases needs more space, but that is wrong, as this cool air tends to contract the

volume of the gases by its cooling effect and the endeavor of all molecules of entering oxygen to come in contact with every molecule of combustible gas (by diffusion) becomes by far more difficult when the furnace gases are expanding.

18 At the rear of this enlarged portion of the combustion chamber, the intermixture of air and furnace gases, mentioned in paragraph 3 of Mr. Bement's paper, occurs principally through the process of diffusion, no attempt being made there, by baffling, to cause what might be termed a mechanical means of mixing of combustible gases and air.

19 The next matter to be considered is the effect of this form of setting, beyond the furnace and combustion chamber, upon the individual boiler efficiency, which efficiency is governed entirely by the difference in temperature between the gases entering the boiler proper and the temperature of these gases discharged from the boiler.

20 With bituminous coal as a fuel, tests have proved that a furnace of this form, if properly designed and manipulated, will produce high temperatures, and it then merely becomes a matter of bringing these high temperature gases into proper contact with the heat absorbing surfaces of the boiler.

21 To accomplish this end, we must see that the solid bulk of furnace gases is broken up on its passage through the boiler, so that no bulks or big masses of gas will pass from the combustion chamber to the flue outlet without giving up to the heat absorbing surfaces a very large percentage of the heat contained in their very centers.

22 This end is well accomplished by impelling these masses of gas against the staggered arrangement of the tubes found in their path of travel through the various passes of this type of boiler.

23 Of course, the slower the rate of gas travel the less the tendency towards the breaking up of these masses of gas will become.

24 Next, and most important, must we see that practically every square inch of the heat absorbing surface is equally bathed by these hot gases, by which, I mean that there must be no places where the hot gases are not constantly moving over all portions of the heat absorbing surfaces.

25 It is questionable whether such an ideal condition can be completely realized, and in attempting to realize it, we must not make sacrifices in other directions which will offset any gain we may obtain toward this desired end

26 Doubtless, many will question the desirability of throttling the flow of gases through the boiler, so as to require a forced blast under the grates in combination with an induced draft at the flue outlet,

for the mere purpose of forcing the gases into a more intimate contact with the heat absorbing surfaces, as Mr. Bement's design requires.

27 A carefully conducted test would be necessary to prove the desirability of such an arrangement and the quantity of steam required to operate both fans must necessarily be charged against the boiler's performance to obtain conclusive results.

28 The advantages to be gained in the practical working of the so called "balanced draft" (referred to by Mr. Bement as being embodied in his design) are not wholly clear to me, although I do not speak from lack of practical experience in this direction and I have heard of certain desirable fuel economies following the installation of this system.

29 Of course, if we can maintain atmospheric pressure throughout the entire interior of a leaky brick boiler setting, we can prevent the infiltration of cold outside air, but with properly built and maintained boiler setting this infiltration may be reduced to a comparatively small item of loss.

30 If we judge from the figures given in Par. 8 of Mr. Bement's paper, his arrangement does not fulfill this condition, as we see that there is zero (or atmospheric) pressure above the fire bed, so in order to establish a positive flow of gases through the boiler, we must have less than atmospheric pressure at the flue opening, and owing to the serious obstacles (*i. e.*, the baffles) placed along this line of gas flow, this draft suction at the flue outlet must be considerable, and with such a diminution of pressure below the atmosphere, air infiltration through leaky boiler settings must occur.

31 Concerning the arrangement of tiles along the lower row of tubes, furnishing a fire-brick roof over the furnace and combustion chamber, this feature can hardly be called new. Babcock & Wilcox have used a similar arrangement for some years in their marine boiler, only, instead of firing through doors in the front of their boiler, they fire through doors placed under the rear header, the grate being placed at that end of the boiler (instead of at the front) and the firebrick furnace roof (supported by the lower tubes) extends from the rear headers, forward, leaving the opening to the tubes at the front end of the boilers.

32 A cut of this setting can be seen on p. 20 of "Marine Steam" edition of 1901, issued by the Babcock & Wilcox Co.

33 Cuts showing similar settings to that shown in Fig. 7 can be seen in the boiler catalogue of the Edgemore Iron Co., edition of 1902.

34 Almost identically the same form of brick as that shown in Fig. 3 was designed by Mr. R. K. McMurray, of this city, which has

been similarly inserted and used with the water tube boilers of the Chelsea Jute Company, in Brooklyn, for a number of years.

35 One feature in Mr. Bement's design which hardly seems desirable, is the reduction in size of the boiler tubes in the bottom row from 4″ to 3½″.

36 The lower rows of tubes are always scale catchers in this type of boiler. The most scale is always found in the bottom row of tubes, a little less in the row above, and less and less impurities are found deposited in each ascending row so that in many plants, the upper rows of tubes are very seldom opened for cleaning.

37 If any change was made in the size of the lower tubes, which are the most perishable, the above facts would indicate the desirability of introducing larger (instead of smaller) tubes, which would not tend to fill up with scale so rapidly.

38 In discussing Mr. Bement's paper, Professor Breckenridge rightly states that there exists too great a division of interests between the boiler makers and the manufacturers of special furnaces, and under such conditions each unwittingly is apt to decrease the efficiency or capacity of the other's apparatus, and the owner of the steam plant is the one who suffers.

39 Having been in the boiler business for a number of years, I know that the boiler manufacturer is not seeking the combined opposition, in trade, of all the special furnace and stoker manufacturers, which would certainly follow should he go into competition with them by pushing the sale of some special furnace or stoker made by him, and further, as no one form of special furnace or stoker is equally adapted to the use of all kinds of fuel, it is better to allow an independent selection of furnaces and their appliances, which will make it possible to select, from the large number now on the market, the one which is best adapted to the existing conditions.

40 As the generation of all the heat necessary for the operation of the boiler (and all the rest of the steam plant) occurs in the furnace, it becomes most important to see that the design of the furnace is such as will produce an ample quantity of heat, in an economical manner, from the fuel available.

41 Placing over a furnace a boiler having a heat absorbing capacity less than the heat producing capacity of the furnace would only lead to an unnecessary waste of heat, while placing over the furnace a boiler of much greater heat absorbing capacity than the heat producing capacity of the furnace, would not only reduce the possible capacity of the boiler, but the money paid for the excess of boiler heating surface would simply be wasted.

42 As the successful operation of the [illegible] plant depends primarily upon the proper operation of the furnace, the furnace should be the most important consideration in steam plant design, and in my practice I have always made it so.

43 After designing the furnace best adapted to the existing fuel conditions, and making provision in it for the reception of a certain variety of grate bars, stationary or mechanical, I next fit a boiler to it, and this practice has led to the highest possible results in fuel economy and steam production.

44 Viewed from this standpoint, in accordance with Professor Breckenridge's suggestion, the special furnace and stoker manufacturers should become boiler manufacturers and turn out the complete steam generating equipment.

45 The possibility of such a departure from the present business arrangement is too impossible to need further argument.

46 There is but one solution to this unfortunate condition, and that is for the steam plant owner to employ a competent consulting engineer who is an expert in both furnace construction and steam generating apparatus and this engineer can then take charge of the entire design and produce a combined furnace and boiler equipment which will give the most satisfactory results.

47 Professor Breckenridge also refers to the 460 trials of various coals under steam boilers at the government fuel testing plant in St. Louis. I also have spent considerable time in tabulating and reviewing the results of these tests as presented in the report issued by the Geological Survey and regret to say that they have proved to be a great disappointment to me, and, in certain ways I have found them incorrect and misleading.

48 In the first place, all of the different varieties of coal have been burned in one single form of furnace and with a very small range of difference in draft pressures. The general poor results obtained in the flue gas analyses show in most cases that the fuel has not been burned properly, and under such conditions its true value is not to be found in the tabulated results.

49 The method of sampling used is either incorrect, or else careless work has been done. This is shown in many cases where the percentage of ash or refuse found by analysis is more than the amount obtained when the same fuel is burned in the boiler furnace. Judging from such results, one would say that they had been burning incombustible matter under the boilers. There is not sufficient draft pressure used in these tests to carry any material amount of solid matter from

the fire bed over into the rear connections of the boiler, so there is no such explanation available to account for such remarkable results.

50 Most of the heat balances given are not correct as I have found that they do not check up.

51 I certainly hope that greater care will be exercised in the future at this station, as there is little reason why they should not do accurate and valuable work there and furnish reliable information which is sadly lacking at the present time.

MR. WILLIAM H. BRYAN The features of this design on which emphasis is laid are the tiled roof of furnace, and the increased number and reduced area of the gas passages among the tubes. There is little or no novelty in either of these. The tiled roof has been used successfully by builders of water tube boilers for years. Designs which leave the lower half of the tube exposed, while covering the upper half, are quite antiquated. A construction of this kind is described as far back as February, 1886, in a paper in Volume 14 of the Proceedings of the American Institute of Mining Engineers. I have in my possession a drawing bearing date of August, 1897, showing a tile for covering the tubes on the lower side. There is also an English patent, granted to Jonath Gresty in 1889, covering a similar tile. The advantages of this method have long been known, particularly with long flame fuels, such as the bituminous coals of the West, which run high in volatile matter. Whether it is of equal advantage with such short flame coals as anthracite and semi-bituminous, is not clear.

2 As to the proposed plan of baffling, the files and records of the drafting offices of many boiler builders, and also the patent office, will show innumerable designs of this kind, very few of which, however, have met with any general adoption. The fact that such an arrangement necessitates increased draft is admitted by the author, who suggests a combination of forced and induced draft. As this is not available in the average plant, and as ordinary drafts would be insufficient, the range of usefulness of the device seems limited. Incidentally, additional complications are introduced, such as a greater number of cleaning doors, and the necessity of cleaning from the side, which is not always easily arranged for. These bafflers are exposed to high temperatures, are quite inaccessible, and the maintenance in reasonably tight condition of the small number usually employed, is difficult. The introduction of two different sizes of tubes in the same boiler will not be looked upon generally with favor. The omission of two rows of tubes increases the space required.

3 Such an arrangement will, furthermore, cut down the capacity of the boiler, not only for regular work at rating, but particularly for overloads. Ability to carry rated load easily, continuously, and economically, and also to develop one-third to one-half above rating in emergencies, is essential in good boiler design.

4 The author dwells upon the value of the chain grate in insuring uniformity of feed of coal. This, of course, is important, but many plants are subject to wide fluctuations of load, and any apparatus to be entirely successful must so feed the fuel as to meet this condition with efficiency and with reasonable smokelessness. Admitting its many good qualities and its usual excellent performance, the claim that the chain grate—even with tiled roof—is "smoke-proof," is sufficiently novel having, so far as known, never before been made.

5 The suggestion of a combined forced and induced draft plant, has of course some merit, although it is not new. It makes it possible to secure atmospheric pressure in the fire box, thus maintaining balanced conditions and preventing leakage of cold air inward, and heated gases outward. Whether this advantage justifies the increased complication of apparatus, first cost, space occupied, and the close adjustment and manipulation necessary to obtain satisfactory results, is doubtful. Even when such a balance is maintained there must be some degree of draft vacuum in the later passages, at which points there would still be a tendency to leakage inward. A better suggestion would seem to be that of an air tight envelope enclosing all the brick work. This, with practically air tight openings, would reduce the possibility of discharges which the author fears.

6 It may reasonably be supposed that boiler builders of wide experience, who have spent thousands of dollars in experimental research, have adopted arrangements of tile which best meet average conditions of service. Naturally they hesitate to change these standard designs. On the other hand, they are usually willing to modify those designs to meet special conditions of draft, fuel, capacity, or space available.

MR. JAY M. WHITHAM The valuable paper by Mr. Bement contains two points which I wish to specially note. In paragraph 6 he describes a system of "Balanced Draft." In paragraph 9 he states "So far as the author is aware, there are no features of the above apparatus which are patented." In order that the Society may not be misinformed, I desire to call attention to Patents 817, 438, 349 and 826, which were issued to one Emb ry

McLean. Apparatuses installed under these patents, and designated as forming a "Balanced Draft," have been installed in many places, and I have conducted tests thereon. A very brief summary of these tests is as follows:

2 In one plant containing three 60″ x 18″ horizontal tubular boilers, each with forty-six 4″ tubes, there was developed with balanced draft an excess capacity of 25 per cent over that obtaining with natural draft, the same grade of semi-bituminous coal being used on each test and the same economy in its use resulting.

3 In another plant having Berry boilers, when using semi-bituminous coal at $3.30 a ton with natural draft, as compared with rice coal at $2.25 a ton with balanced draft, and as compared with buckwheat coal at $2.75 a ton with balanced draft, the capacity developed being the same in each instance and in excess of rating, the use of rice coal showed a commercial saving of 16 per cent and buckwheat 8.6 per cent.

4 In another plant containing six 104 horse power Babcock & Wilcox boilers, semi-bituminous coal at $2.75 a ton, burned with natural draft, was compared with rice coal costing $1.75 a ton, burned with balanced draft. The commercial saving in favor of the use of the balanced draft and cheaper fuel was 29.7 per cent, the capacity developed being substantially the same.

5 In another test on a battery of two 60″ x 15″ horizontal tubular boilers, equipped with Hawley furnaces and using semi-bituminous coal, at $3.30 a ton, with natural draft, as compared with rice coal at $2.35 a ton burned with balanced draft under two boilers of identical size and in the same plant and equipped with common grates, there was a commercial saving of 9.48 per cent, the rice coal developing as much capacity as did the soft coal.

6 In a plant consisting of two 250 horse power Keeler water tube boilers, and using soft coal at $2.74 a ton, with natural draft, as compared with rice coal at $1.85 a ton with balanced draft, there was a commercial saving by the use of the balanced draft of 26.14 per cent, the capacity being the same in each instance.

7 In a plant consisting of Babcock & Wilcox boilers, burning buckwheat coal at $2.90 a ton under natural draft, as compared with rice coal at $2.32 a ton with balanced draft, the capacity being the same on each test, there was a commercial saving of 25.75 per cent in favor of the cheaper fuel.

8 In a plant consisting of horizontal tubular boilers, using soft coal at $2.75 a ton, with natural draft, as compared with buckwheat coal at $2.25 a ton with balanced draft, and also as compared with

rice coal at $1.75 a ton with the balanced draft, the capacity being substantially the same on each test, the commercial saving was 13 per cent by the use of the buckwheat coal, and 29.7 per cent by the use of rice coal.

9 In a plant having two 203 horse power Babcock & Wilcox boilers, using semi-bituminous coal, at $3.05 a ton, with Hawley furnaces, as compared with rice coal at $2.25 a ton with balanced draft, the capacity being greater with the rice coal than obtained with the soft coal, the commercial saving was 11.4 per cent in favor of the balanced draft.

10 Mr. Bement has solved the problem as to what constitutes the merits obtaining with a balanced draft in a furnace. This he explains in paragraph 6 of his valuable article when stating that the combustion is effected with a smaller air supply. In other words, the air used for dilution is a very small quantity, and by the use of this system of draft but little more than the theoretical amount is employed.

PROF. D. S. JACOBUS Mr. Bryan has brought out a number of points on which I intended to speak. All authorities agree that with the proper arrangement of heated brick work and a long enough pass for the gases in the furnace, much can be done in stopping the smoke; but to be efficient, the brick work must be brought to a high temperature, and eventually it will deteriorate and have to be replaced. In some cases the cost of maintaining the brick work may outweigh the increase in the economy through its use, whereas in others the increase in economy may far outweigh the cost of maintenance. In any case, the cost of replacing the brick work is apparent to the user of the boiler, and sometimes he may be hampered in having to throw out the boiler for repairs during a busy season, whereas the gain in economy through using the heated brick work, being distributed over a long interval of time, is not so apparent, and he may therefore be misled into considering that what in reality was an economical arrangement was an unprofitable one.

2 The problem of smoke consumption in a large plant where firemen of various grades of intelligence must be employed, and where it is necessary at times to quickly increase the capacity and in some cases to run with a considerable overload, possesses far greater difficulties than that of the small plant which is run well within its capacity and where expert attendance is available. It is in preventing the formation of a light smoke at certain periods, and the throwing off of the heavier smoke when the boilers are forced, that many of the so-called smoke consuming devices fail.

3 In the discussion by Mr. Ennis, an account is given of some tests with Babcock & Wilcox boilers with oil fuel where these boilers were found to be less efficient than horizontal return tubular boilers.

4 The figures given should not be regarded as a basis for comparing the efficiencies of the two types of boilers when using oil as fuel, because with the proper furnace for oil burning, the Babcock & Wilcox boilers give an efficiency equal to that which Mr. Ennis found for the horizontal return tubular boilers, or 80 per cent. This efficiency has been reached in many tests in San Francisco and elsewhere. In tests made at Los Angeles where these boilers were fitted with the Peabody Oil Furnace and where comparative tests were made, the results being checked by a disinterested engineer, as high as 83 per cent of efficiency was obtained. The day is passed when a particularly high efficiency can be claimed for any special type of boiler. With an efficient furnace and the proper amount of heating surface so arranged that the hot gases circulate properly over it, all good boilers will have nearly the same efficiency.

MR. E. A. HITCHCOCK Mr. Bement states that the principal objects to be secured in the design of setting as described is, first: the attainment of perfect and smokeless combustion, and, second: the full utilization of the boiler heating surface. As regards the first point, my experience with Hocking Valley pea and slack coal on boilers of the horizontal water tube type, 3½-inch tubes, with enveloping tile forming a refractory roof, in conjunction with inclined grate automatic stokers, has been the obtaining of very nearly smokeless combustion and as to perfect combustion, the products at times would contain CO, but not sufficient to make the loss in this direction more than one-half of one per cent.

2 As regards the second point, there is something quite important which must be taken into consideration at time of installation, if this form of setting is to be used. The form of baffling as shown by Fig. 1 may add materially to the efficiency of the heating surface above the lower row of tubes, but on the other hand, the enveloping tile has cut down very materially the large amount of work the lower row is capable of doing on account of practically no radiant heat effect. For example, I have found in the type of boiler spoken of above, containing 4880 square feet of heating surface and rated at 450 horse power, that it was impossible to get the boiler rating with anywhere near reasonable flue temperatures, tube surfaces both inside and out and tiling being in good condition. Observations covering a period of 24 hours would give an average horse power of 334 with a

maximum of 374 while the average flue temperature was 705 degrees F. with a rate of combustion for the pea and slack coal of only 18 pounds per square foot of grate per hour, the ratio of grate to heating surface being 1 to 54.

3 The effect of the enveloping tile in this same direction is well shown in the first report of the U. S. Fuel Testing Plant at St. Louis. The builders' rated horse power for the boiler used was 210 with a ratio of grate to heating surface of 1 to 50.1. The average horse power developed for 70 of the trials given is 195.7 while the average flue temperature of the same series is 578 degrees F., therefore, if we are to use the form of setting under discussion and maintain good efficiency, at the same time obtaining the usual capacities, a much larger number of square feet of heating surface per horse power must be allowed than has been customary, with also an increase of ratio of grate to heating surface.

MR. EMBURY MCLEAN It may be of interest to the members of the Society to know that a combination of forced and induced draft, substantially as described in Mr. Bement's paper, has been applied and thoroughly tested for several years in hundreds of boilers and that the term "Balanced Draft" has been used as the commercial name of the system. The tests made under the well-known A. S. M. E. code of rules and often by prominent members of the Society have almost invariably shown increased boiler efficiency, increased boiler capacity, and the ability to maintain the boiler duty while burning the cheapest grades of fuel, resulting, of course, in marked economy. A table showing the increase in economy and capacity effected by the installation of balanced draft in several representative steam plants is here given. This list includes the plant of the Flatiron building in New York to which Mr. A. J. Herschmann referred in the discussion of Mr. Bement's "Notes on Efficiency of Steam Generating Apparatus," presented at the Scranton meeting in June of 1905.

2 Balanced draft differs from all other systems of combustion in that the amount of air supplied to or entering the furnace is limited to the amount required to burn the coal. The air supplied to a furnace by a chimney is an uncertain quantity, varying with the thickness of the bed of fuel, with the opening of the fire door, and with atmospheric conditions. Therefore, in order to attain accurate control of the air supply, it is necessary to eliminate chimney draft as a factor by balancing the draft.

3 The draft is balanced by throttling the suction of the chimney in relative ratio to the speed of a special type of fan-blower which

supplies air to the ashpit, so that atmospheric pressure is maintained in the furnace chamber. The speed of the fan-blower is controlled by the boiler pressure, and the position of the damper varies in unison with the variations in speed of the blower, being controlled either by steam pressure actuating the blower engine, or by the pressure of the gases in the furnace chamber. The fan blower is so designed that it will deliver approximately a constant volume of air of variable pressure for any given speed. The volume varies with the speed and the pressure varies with the resistance. The pressure in the ashpit, therefore, varies with the thickness of the fuel bed, and the volume of air varies in accordance with the demands for steam made upon the boiler and is limited to the minimum amount of air required to maintain the necessary rate of combustion.

4 Balanced draft increases both the capacity and efficiency of the boiler and furnace:

a By attaining the highest possible temperature of the gases of combustion. When the supply of air has reached the proper amount for perfect combustion, *viz:* approximately, 12 pounds of air to each pound of coal, the furnace is developing its maximum temperature. Any excess of air beyond this amount will reduce the temperature of the furnace by diluting the gases with the air that does not combine with the coal. As the boiler absorbs heat in proportion to the difference of temperature between the gases and the boiler, maximum temperature of furnace gases gives the maximum rate of absorption of heat by the boiler.

b By increasing the time of contact of the gases with the heating surface. As the volume of gases generated is reduced to a minimum for a given quantity of coal burned, the velocity of their travel through the boiler can be proportionately reduced. As time is an element in the absorption of heat by the boiler, the greater the time the gases are in contact with it, due to the reduced velocity, the greater the proportion of heat in the gases absorbed by the boiler.

c By increasing the effective heating surface. The reduced velocity of the gases and their even distribution and diffusion to all parts of the heating surface makes every inch effective instead of having a considerable portion of the heating surface pocketed, or out of the direct line of travel of the gases from the edge of one baffle to the next.

TABLE I

THE INCREASE IN ECONOMY AND CAPACITY EFFECTED BY THE INSTALLATION OF BALANCED DRAFT IN REPRESENTATIVE STEAM PLANTS

NAME OF FIRM	KIND OF DRAFT	DATE OF TEST	HOURS DURATION	TYPE OF BOILERS	RATED H. P.	H. P. DEVELOPED	INCREASED CAPACITY WITH BALANCED DRAFT	KIND OF COAL USED	COST OF COAL PER TON	POUNDS COAL CONSUMED	WATER EVAPORATED FROM AND AT 212° F.	WATER EVAPORATED PER LB. DRY COAL	WATER EVAPORATED PER LB. COMBUSTIBLE	COST OF 1000 H. P. PER HOUR	SAVING EFFECTED
							Per cent		Dollars	Pounds.	Pounds.	Pounds.	Pounds.	Dollars	Per cent
Standard Oil Co., Bayonne, N. J.	Forced	2 tests	‡8	W. T.	250	275		Rice		10,433	76,092	7.29	9.35		
	Balanced	2 tests	‡8	W. T.	250	302	10.0	Rice		8,797	75,798	8.59	10.38		15.2
American Smltg. and Rf. Co., Perth Amboy, N.J.	Forced	Dec. 18, '04	20	W. T.	500	505		Rice	1.75	47,282	348,145	7.35	9.22	4.10	
	Balanced	May 26, '05	10	W. T.	500	769	52.3	Rice	1.75	23,207	214,134	9.20	10.63	3.28	20.0
Baldwin Locomotive Works, Philadelphia, Pa.	Natural	3 tests	9	W. T.	600	587		Soft	2.70	21,114	182,071	8.62	9.71	4.82	
	Balanced	3 tests	9	W. T.	600	634	8.0	Buck	2.25	23,583	196,792	8.24	9.77	4.21	12.6
	Balanced	3 tests	9	W. T.	600	643	9.5	Rice	1.75	21,978	200,294	9.10	10.67	2.97	38.4
	Balanced	1 test	9	W. T.	600	799	36.1	Buck	2.25	28,177	247,946	8.80	10.29	3.94	18.3
Albany Water Works, Albany, N. Y.	Steam Jet	Nov. 14,'05	8	H. R. T.	340	356		Rice	2.07	14,721	107,055	7.27	8.03	5.26	
	Balanced	Dec. 5, '05	8	H. R. T.	340	420	18.0	Rice	2.07	12,479	118,250	9.46	11.57	3.79	28.0
	Balanced	Dec. 6, '05	6	H. R. T.	340	481	35.0	Rice	2.07	9,979	102,008	10.22	11.71	3.52	33.0
Hudson R. El. Power Co., Utica, N. Y.	Natural	Jan. 5, '06	10	W. T.	488	371		Mix*	2.56	14,220	107,204	9.01	9.91	4.37	
	Balanced	Jan. 13, '06	10	W. T.	488	617	66.3	Mix†	2.13	22,232	212,715	9.57	11.20	3.43	21.5
Pratt & Whitney, Hartford Conn.	Natural	Sep. 18, '06	9½	W. T.	300	270		Soft	3.80	9,556	88,523	9.26	9.81	6.51	
	Balanced	Sep. 19, '06	9	W. T.	300	345	27.0	Soft	3.80	10,214	107,269	10.50	11.13	5.81	10.7
	Balanced	Sep. 20, '06	9½	W. T.	300	273		No. 3 B	2.30	9,148	89,489	9.78	11.13	3.84	41.0

American Locomotive Co., Paterson, N. J.	Natural	5 tests	§60	W. T.	300	275		Soft	2.98	63,885	569,922	8.93		5.15	
	Balanced	5 tests	§57	W. T.	300	308	12.0	Rice	2.00	70,040	606,202	8.65		3.56	30.8
	Balanced	Sep. 26, '06	10	W. T.	300	369	34.0	Rice	2.00	14,417	127,275	8.83		3.48	32.4
Perth Amboy Chem. Co., Perth Amboy, N. J.	Natural	Dec. 18, '05	6	W. T.	120	124		Pea	2.80	3,750	25,623	6.83	8.15	7.10	
	Balanced	Jan. 10, '06	6	W. T.	120	185	49.0	Buck	2.20	3,956	38,294	9.57	11.80	3.96	44.0
Broad Exchange Bldg., New York.	Natural	2 tests	8	W. T.	350	317		Buck	3.50	20,250	153,134	7.50	9.00	7.19	
	Balanced	2 tests	8	W. T.	350	310		Rice	2.50	21,250	148,818	7.00	8.34	5.50	23.5
Bement, Miles & Co., Philadelphia, Pa.	Natural	Oct. 16, '05	8	W. T.	135	132		Soft	2.70	4,104	31,809	7.75	8.83	5.37	
	Balanced	Oct. 17, '05	8	W. T.	135	195	47.7	Rice	1.75	6,032	47,260	7.83	9.16	3.45	35.0
Land Title and Trust Bldg., Philadelphia, Pa.	Natural	Sep. 14, '05	10	W. T.	231	226		Buck	2.90	9,216	78,022	8.46	10.80	5.65	
	Balanced	Sep. 10, '05	10	W. T.	231	259	14.6	Rice	2.32	9,827	89,304	9.09	10.99	4.11	25.75
Strawbridge & Clothier, Philadelphia, Pa.	Natural	July 25, '05	8	W. T.	190	209.4		Buck	3.25	6,092	57,799	9.49	11.23	5.27	
	Balanced	Aug. 2, '05	8	W. T.	190	227.4	8.59	Rice	2.25	6,881	62,759	9.09	10.96	3.81	27.2
Haverford College, Haverford, Pa.	Natural	Nov. 8, '05	8	W. T.	150	90		Buck	2.65	3,509	24,860	7.09	9.64	5.76	
	Balanced	Nov. 9, '05	8	W. T.	150	152	68.0	Rice	2.15	4,943	42,379	8.55	10.78	3.87	32.7
Flatiron Building, New York.	Natural	Sep. 20, '04	12	W. T.	340	267		Soft	4.00	10,440	102,065	9.77	10.60	6.40	
	Balanced	May 2, '05	10	W. T.	340	383	43.4	Rice	2.68	12,520	120,400	9.61	11.25	4.20	34.3
	Balanced	May 9, '05	10	W. T.	300	388	43.8	Soft	4.00	11,606	133,622	11.50	12.10	5.33	16.7
Mutual Life Ins. Bldg., New York.	Natural	Aug. 14, '05	9	W. T.	300	139		Brkn	4.95	4,643	43,080	9.28	11.21	8.20	
	Balanced	Aug. 16, '05	9	W. T.	150	167	20.1	Buck	3.25	5,130	51,820	10.10	11.95	4.95	39.6
Fidelity Mutual Life Bldg. Philadelphia, Pa.	Natural	Mar. 12, '05	9	W. T.	200	183		Buck	3.75	7,366	63,150	8.56	10.82	7.05	
	Balanced	Mar. 11, '05	9	W. T.	200	217	18.6	Rice	2.75	7,776	75,000	9.63	12.35	4.60	33.8

* A mixture of 30 per cent screenings and 70 per cent soft coal
† A mixture of 84 per cent screenings and 16 per cent slack
‡ Hours each
§ Total time of 5 tests

The capacity is further increased by the possibility of effectively burning a greater amount of coal. As the volume of gases from a given quantity of coal burned is reduced by the exclusion of excess air, the quantity of coal effectively burned in a given time can be proportionately increased.

5 Aside from the exhaustive evaporation tests, the results of some of which are given, the above statements are confirmed by the increased percentage of CO_2 in the flue, demonstrating a great reduction in volume in flue gases, and a like reduction of heat units here wasted; also by the reduced flue temperature.

6 Analysis of the flue gases from a furnace operated by either forced draft, induced draft, or chimney draft, will rarely show an average amount of CO_2 greater than 8 per cent, while with balanced draft an average result of at least 16 per cent of CO_2 is usually obtained. The increased percentage of CO_2 alone proves that balanced draft reduces the air supplied to the furnace to practically the theoretical amount required for perfect combustion, and that with forced draft, or induced draft, or chimney draft, about 100 per cent more air than is required is passed through the furnace.

7 That only one half the ordinary amount of gases have to be carried away has been demonstrated in a most practical manner in one prominent plant where before its installation additional stack capacity had been ordered.) The use of the system led to the canceling of the order and the abandoning and dismantling of one half the stack capacity already installed. It is a fact beyond question that the balanced draft system will double the horse power capacity of the stack. Balanced draft reduces the function of the stack to merely that of removing the gaseous products of combustion from the furnace.

8 In a boiler of the Babcock and Wilcox type, about 80 per cent of the total evaporation is effected in the tube surfaces between the front headers and the first set of baffle plates at the bridge wall. A boiler of this type can be operated with the balanced draft system without baffle plates, without reducing the efficiency, and with a large increase in the evaporating capacity. In other words, a boiler so equipped would evaporate between 6 and 7 pounds of water per square foot of heating surface at substantially the same efficiency that it now evaporates 3.4 pounds of water when operated at its present rated capacity.

9 Nor are increased capacity and economy the only advantages resulting from such a condition. The life of the boiler is greatly increased and the expense of maintenance and repairs reduced

because there are no sudden changes in temperature due to the inrush of cold air when the fire door is opened. The strains due to unequal expansion and contraction and the disintegration of the furnace lining caused by these sudden changes of temperature are avoided. The deposit of scale is distributed more evenly over the entire heating surface, instead of accumulating in the bottom row of tubes, which, incidentally, is conclusive evidence that the ordinarily ineffective portions of the boiler are made effective. The time between boiler cleanings can be doubled with safety, reducing the maintenance expense and the time the boiler is out of service.

10 While balanced draft accomplishes so much in regard to capacity, economy, and generally improved boiler room conditions, it does not eliminate the smoke nuisance. As is well known and has been emphasized by the discussion at Scranton, there are three important conditions necessary for complete combustion and smokeless stack

a Proper air supply

b Proper temperature

c Proper mixture of the air and the gases

11 Balanced draft accomplishes the first two and Mr. Bement has described an effective method of accomplishing the third requisite by passing the gases under a long refractory tile roof fastened to the bottom tubes of the boiler. This combination, as he says, produces a "smoke proof" furnace.

PROFESSOR KENT I find here Mr. Embury McLean's discussion on balanced draft, I do not think it is a fair test to take an ordinary boiler and get a very low result, far below what one ought to get with that boiler in the usual conditions of everyday practice, and then publish that result in comparison with a fairly good result obtained from the same boiler when fitted with some patented appliance, claiming that the apparent saving in fuel is due to the use of the appliance. It is not a fair statement of the difference between the results "before and after taking," as you might say. I once had to make a test with an appliance and on the face of the returns, there appeared to be 20 per cent better economy as compared with the test without the appliance, but in the latter the results were very bad. I reported that the results of our tests showed nothing except that they should be repeated, and that just as good results as we had obtained with the appliance had often been obtained in an ordinary boiler, the same as the one used in these tests, a return tubular, with the same coal, without any patent device of any kind.

MR. EMBURY MCLEAN Attention has been called by Professor Kent to a tabulated statement of tests showing improved results effected by balanced drafts and the criticism has been made that the comparisons were based on conditions before the application of balanced draft, which were not normal. I wish to say that in every one of these tests the conditions were exactly the same in the tests made before the balanced draft was introduced as after, and many of these tests have been made by members of this Society in accordance with the code of rules prescribed by this Society, so that I think the results are reliable and worthy of note. I might also call attention to the fact that many of these savings are very high, amounting sometimes to 40 per cent. No claim is made that these great savings are due entirely to increased boiler efficiency effected by balanced draft. They are commercial results and are largely due to the fact that with the balanced draft system a much cheaper grade of coal could be used than was otherwise possible and still maintain the boiler duty. The results of the tests show with great uniformity an increase of horse power capacity of the boiler, increase of boiler efficiency, and the ability to burn the cheapest grades of fuel economically.

THE AUTHOR There has never been an agreement between Professor Kent and myself as to the capacity of the tile roof furnace for smokeless combustion. I am disposed to consider that it is much greater than he, and to support my opinion, I will say that in no case whatever within my knowledge, when coal from Iowa, Missouri, Illinois, Indiana, and Western Kentucky, has been burned in an apparatus of this kind, has there been any smoke, irrespective of thickness of fire or strength of draft, although minimum draft has not been below 0.075 of an inch of water over the fire in any of the cases observed. This, of course, is very low, and should it become lower, whether there would be a tendency for carbon to go free or pass away in the form of CO is an unsettled question. At all events, with ordinary chimney heights and draft conditions, thickness of fire or any amount of air supply has cut no figure in the results so far as smokelessness is concerned, and means to study this has been afforded by the Harrison Street plant of the Chicago Edison Company, which has been equipped with these furnaces for several years.

2 As to the provision for increased air supply, I really wish that it were necessary. It is not, however, because there is always an abundance of air; in fact, an undesirable excess with every chain grate fire, and if the stoker could be so arranged that there would

naturally not be a sufficiently large air supply, the most important step in the solution of the problem of high efficiency would be assured, because it would then be a very simple matter to provide means whereby additional air could be admitted according to requirements.

3 Relative to the per cent of CO_2 obtainable, according to analysis, it has been as high as 16 or 17 per cent in this type of furnace when equipped with a chain grate stoker, with a draft, however, not to exceed 0.15 of an inch of water over the fire, and an econometer attached has shown it above 17 per cent for a period of four hours, and, at occasional intervals under peculiarly favorable conditions, the econometer needle has swung as high as 19, and calibration of the instrument between 4 and 14 per cent CO_2 showed it to be quite accurate. Above this point, it was not feasible to check it by analysis, although there was no occasion for its accuracy to be doubted above 14 per cent, but when drafts became stronger, the CO_2 dropped and excess of air increased quite rapidly.

4 In reference to the balance draft insuring complete combustion with a smaller air supply, the meaning is that in the case of the tile roof furnace described, there would be no question concerning complete combustion under any operating conditions, and by the use of a combination of forced and induced draft which would bring about the balanced condition, there would be less leakage of air into the furnace chamber. The statement would have been more to the point had it been framed as follows: that the use of the balanced draft prevented some leakage which would occur under conditions of a partial vacuum in the chamber. The two examples of results secured in the tests with and without the balanced draft, are, of course, very low, and were only quoted because they were absolutely comparable, boilers and operating conditions being exactly the same in each case with the exception of difference in draft, and the data were selected from other records which had been produced for other purposes than that of this paper.

5 Mr. Carey calls attention to the fact that no mixing devices are placed in the furnace chamber beyond the bridge wall for the purpose of effecting a mechanical mixing of the gases. This is because experience has demonstrated that it is not necessary when a chain grate stoker is used, on account of the size and massiveness of the flames not being sufficiently great to prevent their burning away naturally before the exit from the furnace is reached. With different conditions of coal feeding than that assured by a chain grate, it is most essential that these mixing devices be employed as has been fully discussed elsewhere.[1]

[1]Journal Western Society of Engineers, December, 1906.

6 There are two ways of reducing leakage into boiler settings; one, to lessen the vacuum therein; the other, as suggested by Mr. Carey, to use better settings, both of which schemes can be employed at the same time with advantage.

7 I am pleased to have the testimony that the application of fire brick tiles over the fire is not new, because it helps to demonstrate the fact that there is no uncertainty as to their usefulness and that their value has been proved. The form of furnace roof which the Babcock & Wilcox Boiler Company has used, however, is more on the order of the T tile baffle used by the Heine Boiler Company, and is applied to its marine type of boiler for the purpose of obtaining some approximation to the heat distribution over the tubes afforded in its regular standard form of stationary boiler, rather than for the purpose of securing any benefit from better combustion.

8 It is my understanding that a considerable number of people have designed a tile, either for the same purpose or similar to that shown by me in Fig. 2, and I am glad that it is so, because, as before mentioned, it demonstrates the fact that the particular improvement which I am advocating is not made up of untried and uncertain features.

9 As to the matter of using 3.5 inch tubes in the bottom row, while those in the rest of the boiler are all 4 inch, I recognize that this is a disadvantage, justified only in view of the fact that it is accompanied by the advantage of offsetting the harm occasioned by the two sizes. The only substantial objection is that two turbine cleaners are required; also, that if tubes are carried in stock, one or two 3.5 inch should also be on hand, and that a different sized expander will be required in replacement. The cost of these three features is readily calculated and determined, and when once provided for, cannot strictly be considered as a continuing source of expense. On the other hand, the advantage to be derived from the use of 3.5 inch tubes is that a thicker necked tile can be used, insuring a greater life to the furnace roof and decreased cost in its application, because with the Babcock & Wilcox type of boiler, the horizontal tube centers are not exact. They may vary as much as half an inch, therefore tiles must be made so that they will compensate for this variation, and with 4 inch tubes the space between them is, if anything, rather narrow for the most desirable results, although a considerable number of the Babcock & Wilcox type of boilers have been changed and some new ones built, wherein the tile roof furnace has been very successfully applied to 4 inch tubes.

10 I am much pleased to have Mr. Bryan's testimony to the

effect that so many features of the design submitted are old and devised by other people, and I thank him for presenting such valuable information, although in this connection I should properly call attention to the fact that it was not the intention to intimate that the design which I submitted in Fig. 1 was new, but rather that it was an improved form, and as such, only in contrast with prevailing practice could it be considered as a novelty.

11 As to the accessibility of baffles and effect of high temperature there has never been any difficulty encountered. The rear baffle

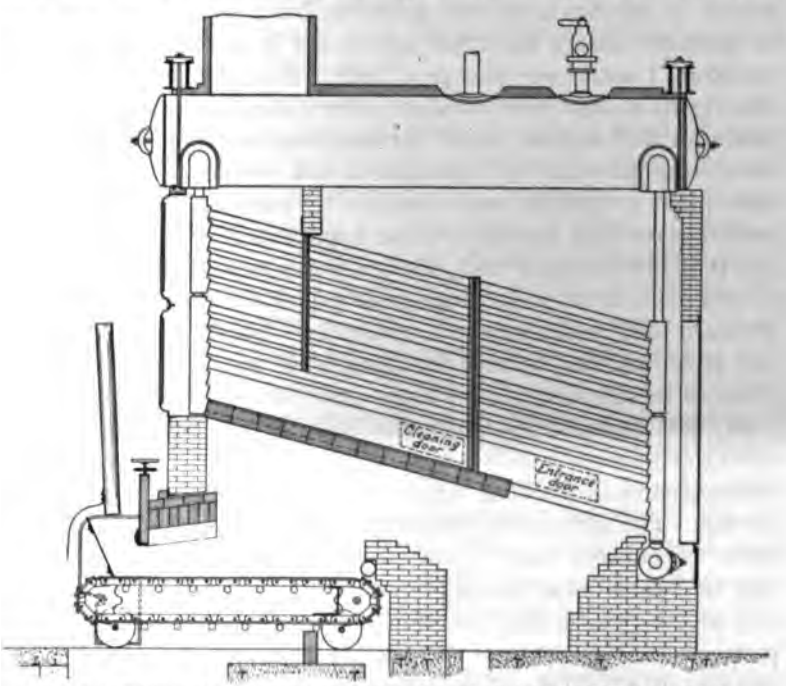


FIG. 8 IMPROVED BOILER SETTING WITH SHORT IGNITION ARCH

would be most subjected to heat, and for that reason I suggest the extension of the furnace roof a considerable distance beyond this rear baffle, so that the hot gases will be compelled to travel a considerable distance across the tubes before they can reach this baffle, or in other words, instead of setting the rear baffle at the end of the roof, I place it a considerable distance forward. As to the matter of accessibility, it has seemed to me desirable to add a door in the setting, giving access to the chamber between the bottom row of tubes and those above in the rear part, as shown by the entrance door in Fig. 8.

12 Relative to such an arrangement as I have shown having the effect of cutting down the capacity in regular work and particularly at overloads, Mr. Bryan is greatly mistaken, because the opposite is the fact, the effect being to increase the capacity rather than to diminish it. This is because the high furnace temperature causes more coal to be burned with the same strength of draft than would be the case if the fire were directly exposed to the boiler.

13 The criticism applying to the chain grate is that it is not suitable for wide fluctuations in load, and as far as this matter is concerned, no furnace is, strictly speaking, but I dare say that it would be conceded that a hand fire approaches it as closely as anything, therefore, I would say that in a large rolling mill plant in Chicago chain grate stokers were installed under water tube boilers to produce steam for mill engines, which arrangement everyone will, no doubt, concede as affording an intermittent and irregular service. In the same plant are similar mills operated by hand fired boilers, and the records show that the chain grate apparatus is more economical in fuel than are the hand fired, but it is not necessary to go into details on this score, because the chain grate stoker is handling every variety of steam load, and doing so successfully. Nearly all of the electric and street railway current in Chicago, as well as other important cities, is being generated on chain grate stokers with great success.

14 Mr. Bryan states that boiler builders of wide experience have spent thousands of dollars in experimental research, and have adopted arrangements of baffling which best meet average conditions of service. The intimation apparently is that they have arrived at better conclusions than I, and on this point I presume my opinion may be considered as having been given and no final answer is obtainable at the present day, therefore, I propose to Mr. Bryan that we postpone the settlement of this feature until some time in the future, and then it will no doubt be apparent who is right.

15 In reply to Mr Whitman, my remarks about patented features of the apparatus described, apply only to the illustration, Fig. 1, and I did not consider the balance draft as any portion of it, therefore, I am very glad to make this point clear, because it is not the intention to mitigate in any way the value of the various patents mentioned.

16 Dr. Jacobus has called attention to a very interesting feature of the problem, and one, too, which would be a sufficient subject for a paper in itself. This is the deterioration of furnaces due to high temperature.

17 A good many forms of brick work have been employed that are expensive to maintain, owing to the fact that self supporting

brick arches and various baffling walls have been employed, which were so located that they not only accumulated a large quantity of heat, thus attaining a high temperature, but the opportunity for such heat to escape by radiation to outside walls is very limited. As a general thing these forms of construction have thus far been expensive to maintain, but in the scheme shown in my paper, the brick work forming the tile roof, or in other words, that portion of the construction equivalent to an arch is carried by the tubes of the boiler, therefore is, in fact, water cooled, and for this reason does not attain the high temperature reached in many other forms of construction. Up to the present time, the maintenance with this form of furnace has not been excessive.

18 The first application of tile roof furnace of which I am aware, was in the station of the Chicago Edison Co., where some six years ago Heine boilers served with chain grate stokers were equipped with the form of encircling tile described in the paper. The annual average cost for maintenance of brick work in these furnaces is $250. Compared with this, the furnace maintenance under some of the latest installations of B. & W. boilers in Chicago wherein the standard design of setting is used, is $170 per annum. These two apparatus may be taken to represent extreme conditions of high and low furnace temperatures. In one there is no heat abstracted from the fire chamber until the gases have reached the rear end of the boiler. In the other, the front end of the boiler is exposed immediately above the fire chamber. There is a saving in fuel of at least $1000 per annum due to complete combustion in the case of the tile roof apparatus as compared with the other, which leaves a very large margin in favor of the tile roof design, not taking into account the freedom from smoke, which is beginning to have a commercial value of no small moment.

19 Dr. Jacobus has, however, contributed a suggestion of great value, in calling attention to the fact that various forms of brick work construction may be a serious source of expense rather than gain, and much detailed study of refractory materials and their employment in this connection is justified, because many applications are not so simple and durable as that shown by the illustration in my paper. It is probable that future work along this line will develop a steam generator so designed, that there will be a limited amount of heating surface exposed in the furnace chamber for the particular purpose of abstracting a portion of the heat, so that the maximum attainable temperature may be limited. While the high temperature is in itself instrumental in securing complete combustion,

it is not necessarily essential, because the [illegible] ected at a temperature which would have but little effect on brick work. In this connection the Edgemoor Iron Co. has brought out a design wherein the side walls are composed of special blocks of refractory material mounted upon water cooled side tubes. Thus the sides and the tile roof of the furnaces are both cooled by water pipes which are parts of the boiler.

20 Referring to the problem of smoke prevention in large plants where the load varies, I will say that with the tile roof furnaces in the Harrison St. Station of the Chicago Edison Co. no smoke is made with maximum or minimum load when furnaces are in operation; in fact, the chimneys always present the least evidence of activity when the load is the highest, and at no time while the fires are in operation is it possible to obtain in a photographic plate, indication of anything passing from the chimneys.

21 The long ignition arch adds to the length of the setting, and consequently in many cases necessitates a considerable real estate and building investment cost. For this reason I prefer the design shown by Fig. 8, which illustrates a boiler recently made to my specifications.

22 In reply to Professor Hitchcock, I will say his conclusion that the presence of a tile furnace roof causes a reduction in capacity is probably based on insufficient data, the cause being elsewhere, as in an extended experience I have failed to observe such effect.

No. 1126

PRODUCER GAS POWER PLANT

An Inquiry into the Operation, Efficiency, and Construction of a Typical Modern Industrial Plant

By J. R. BIBBINS, PITTSBURG, PA.
Junior Member of the Society

1 With all the present activity in power development for various purposes, industrial or otherwise, the value of the simple producer plant used exclusively for power generation seems to have been somewhat overlooked or at least questioned. Gas producers, especially for bituminous fuels, are quite familiar in metallurgical work, notably in the various iron and steel industries; and although the problem of gas purification presented in power work is somewhat more serious, yet experience has indicated several fairly simple methods of solution. The ability of the modern gas engine to take the place of the steam engine in general power work has likewise been questioned, as well as the capacity of gas engine and producer to work together harmoniously under widely varying load demands.

2 Fortunately neither of these charges is founded on a basis of actual conclusive experience, and it is the purpose of this paper to present some practical data upon the operation of a thoroughly representative commercial gas power plant; one in which a high measure of success has been obtained through intelligent engineering and supervision. Even though some minor improvements might still be suggested, the fact remains that this gas power plant is operating week in and week out, 24 hours per day, 6½ days per week, on a fluctuating manufacturing load, with a fuel consumption fully one-half that of a modern steam plant of like character and suited to the same work. On an average of half load this 450 kw. plant ordinarily consumes from 2 to 2¼ pounds of coal per k. w. h. and, on heavier loads, has reached as low a consumption as 1½ pounds per k. w. h. in regular daily running. During heavy loads the plant has repeatedly developed without the battery 530 kw. on maximum fluctuations which represents an overload of 18% rating. Furthermore, with the excep-

Presented at the New York meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

tion of the engineers in charge during the two watches, the plant is operated by attendants originally quite unskilled in gas work; up to the present writing, however, no complete interruption of service, traceable to defective equipment, has been recorded.

3 These facts are thought to be sufficiently impressive to warrant their presentation to the Society, particularly as this plant may be regarded as exemplifying modern engineering practice and the service resulting therefrom. It is hoped that the considerable descriptive detail appended will be exc s more or less essential to a full appreciation of the subject. The choice of a single example seemed to provide a better opportunity for etailed treatment.

CHARACTER OF SERVICE

4 The plant in question ser the entire Gould Manufacturing properties at Depew, a suburb of falo, N. Y. Two complete works are located here; one devoted to the manufacture of storage batteries and the other to the manufacture of railroad specialties, principally automatic couplers. The latter contains a large and well equipped steel foundry. Both e electrically driven and lighted throughout from the central p wer plant.

5 Contributing to the stat n l d are a large number of labor saving machines of different typ ch as electric traveling cranes, charging tables, transfer locomoti ele ators, conveyors, fans, pumps and machine shop tools. The stor b ttery works also use considerable current at times for "forming" ry plates.

TA E 1

EQUI r DATA

450 K. W. PRODU C ENGINE POWER PLANT

Service—Power, some lighting.
Capacity of Plant—450 kw.
Number of Units—Three, 150 kw.
Distribution system—D. C. two wire.
Pressure—250 volts, normal 230.
Power Building—45′x 61′ inside.
Height of roof trusses—28½′.
Height of basement—9′.
Total area per kw.—6.1 sq. ft.
Net area of unit—15′x 33½′.
(With 6 ft. passageways.)
Net area unit per kw.—2.87 sq. ft.
Walls—Red brick, exterior pilasters, limestone trimmings, steel frame work.

Roof—Wood, tar and gravel, steel trusses, monitor.
Floors—Steel, wood, ¾″ maple finish.
Basement floor—Concrete.
Foundation—Concrete.
Crane—Hand power, tons.
Producer Building—Steel framework.
Corrugated iron walls and roof.
Charging floor—Boiler plate.
Cooling Pond—1,000,000 gals.
Dimensions—280′diam. x 93′ wide.
Area (Power Plant) 7,300 sq. ft.
Area (Producer Plant) 7,500 "
Total, 14,800 "

FIG 2 INTERIOR OF POWER STATION
IGNITER CABINET AT REAR WALL, STORAGE BATTERIES IN BASEMENT

Depth—Normal 10′.
Holder—36″ diameter, single lift, 15,000 cu. ft.
Coal used—Bituminous run of mine.
Sources—Buffalo, Rochester & Pittsburg R. R.
Price—$2.30 per ton.
Heat value—13,500 B. t. u.
Engines—Westinghouse three cylinder, vertical gas engines.
Type—Single acting four cycle.
Capacity—235 B. H. P., 260 maximum.
Normal speed—200 r.p.m.
Size cylinders—(3) 19″x 22″ stroke.
Ignition—110 volts and 8 volts.
2 sets four cells storage battery.
1 motor generator set. ½ kw.
Cooling Water (jackets)—Motor driven centrifugal pumps. Two 2″ Worthington "Volute." 15 H.P. motor 1450 r.p.m.
Cooling Water (Scrubber)—2-stage motor-driven. 2″ Worthington "turbine" type. 15 H.P. motor.
Compressed Air—100 lbs. from works, also 6″x 6″ Rand duplex single stage compressor. 10 H. P. motor.
Generators—Westinghouse compound wound. Direct current.
Capacity—150 kw., 250 volts.
Switchboard—250 volt D. C.
Producers—Loomis-Pettibone.
Type—Bituminous, duplex intermittent blast. 3′–8′ diameter.
Boiler—5′ dia. vertical tubular, utilising waste heat.
Wet Scrubber—6′ dia., vertical, coke, water sprays.
Dry Scrubbers—Two 9½′ dia., in parallel; excelsior, 2 layers.
Valves—gear lift, water cooled.
Exhauster Roots—Simple engine drive.
Gas Main—12″ diameter.
Gas Risers to Engine—8″.
Fittings—Screwed.
Valves—Chapman gate.
Coal Handling—Bucket elevator, motor driven.

6 Although the power station load is smoothed out to some extent by the overlapping of demands from these various sources, yet the larger machines pull heavily upon the system with the result that the load at the station bus bar is subject to violent fluctuations, easily 80% above or below (on light loads 100%) the general averages. As no system of notification is in force, the power station cannot be apprised of anticipated demands from the several production departments of the works. The storage battery forming load is, of course, steady while it exists, but it is liable to be abruptly thrown on or off at any time.

7 Several typical runs are shown in the accompanying logs, Fig. 3a, 3b, 3c, 3d, for April 13, July 11-13 and September 25, 1905, respectively. Although the recorded output is fairly steady through the day, the fluctuations correspond in some cases to overloads of 15 20% on the engines.

8 The original plant was entirely capable of handling these fluctuations, but on account of doubling the steel plant load and adding electrically driven air compressors, an auxiliary storage battery[1] was

[1] This battery, however, was not placed immediately in service and does not affect the results presented in this paper except in the matter of capital costs.

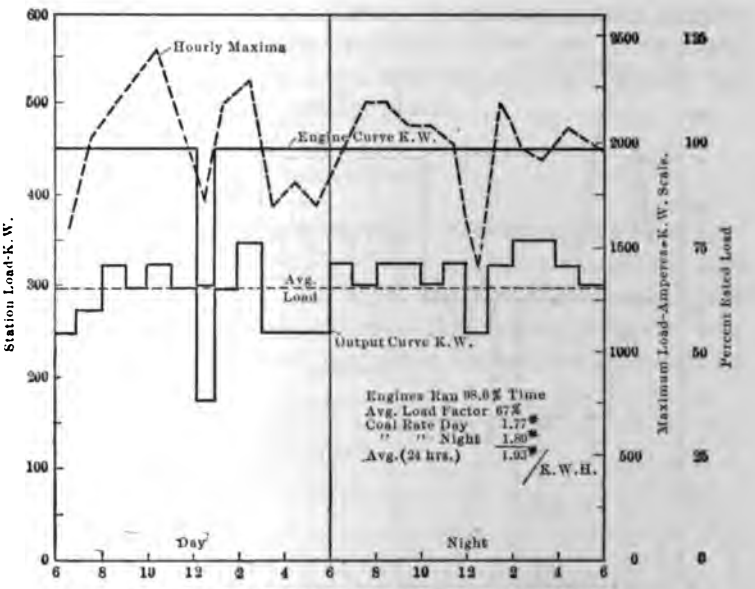


FIG. 3a LOAD DIAGRAM GAS ENGINE PLANT
APRIL 13, 1905

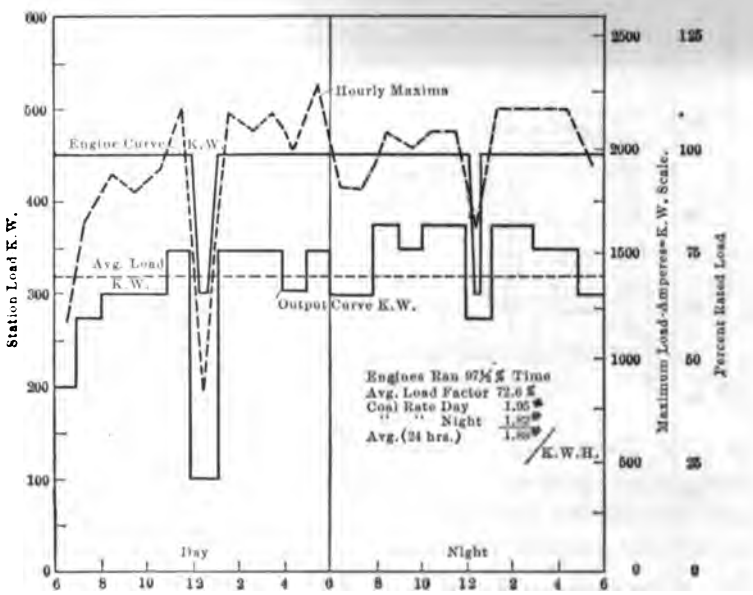


FIG. 3b LOAD DIAGRAM GAS ENGINE PLANT
JULY 11, 1905

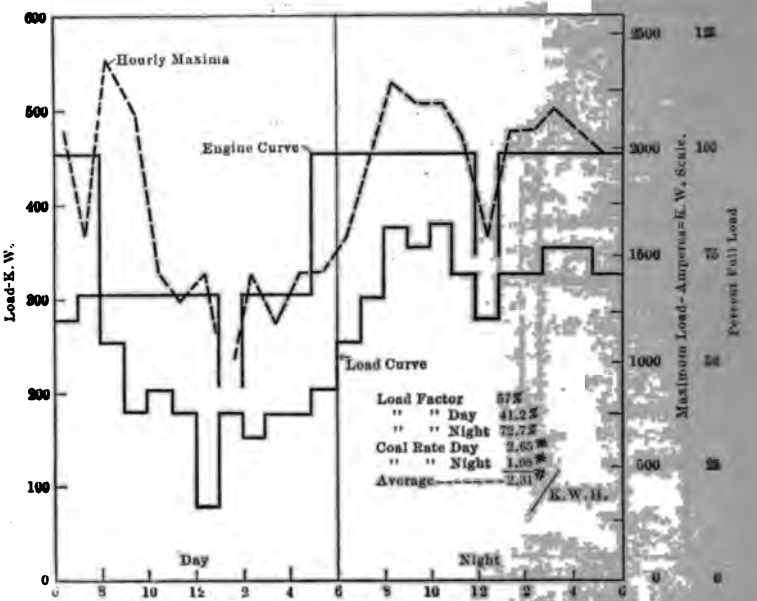


FIG. 3c LOAD DIAGRAM 450 K. W. GAS POWER PLANT
JULY 13, 1905

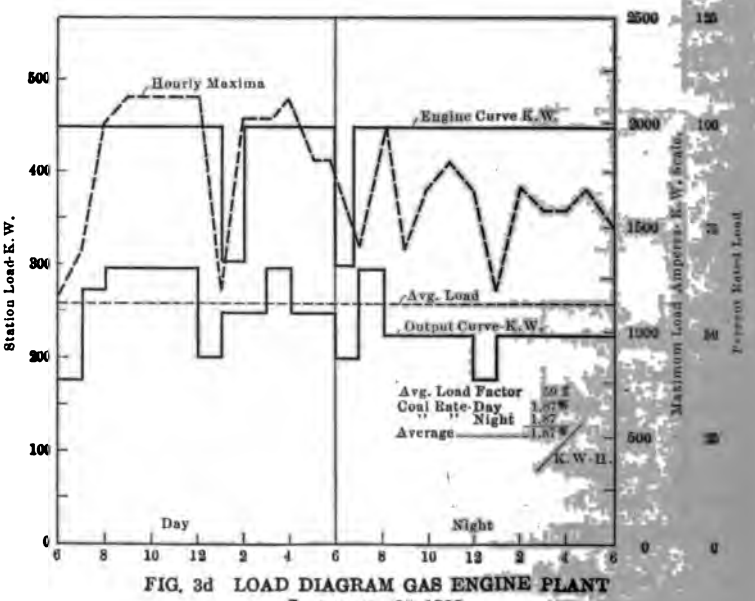


FIG. 3d LOAD DIAGRAM GAS ENGINE PLANT
SEPTEMBER 25, 1905

recently installed for the dual purpose of securing a more constant load on the engines with higher economy of fuel, and of increasing the average load. Formerly it was necessary to keep the spare unit constantly in service to tide over the peaks.

PLANT DUTY

9 From the daily records of the plant an excellent idea of its operative efficiency may be obtained. These records, although not elaborate, are carefully kept and show not only the output and duty of the plant but also the maximum loads that occur during the hour. A digest of a typical day's run is given in Table 2 and shows contin-

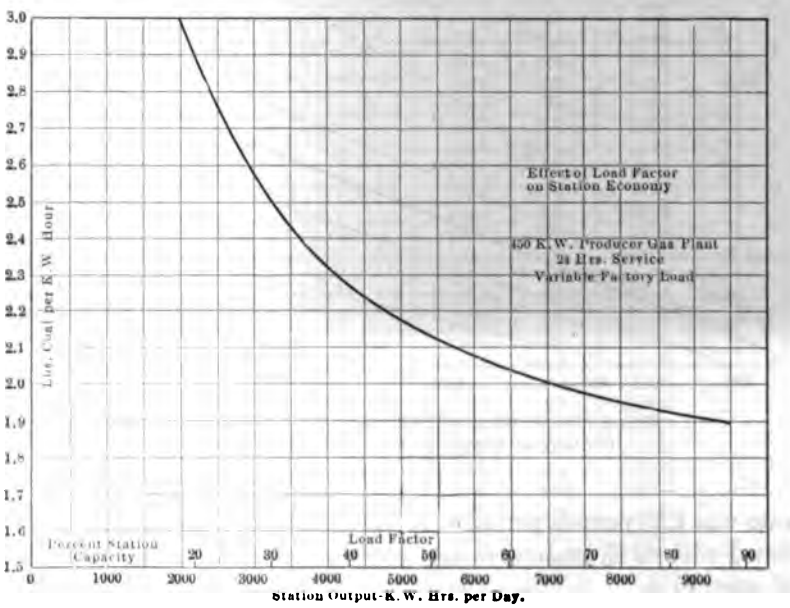


FIG. 4 RELATION OF FUEL RATE TO STATION LOADING FACTOR (PLOTTED FROM OBSERVED DATA)

uous operation except at noon and midnight; to be exact, 97% of the elapsed time. The load averaged 263 kw., or 58% of the generating capacity in service with nine full load hourly maxima and five equivalent to 8% overload. The average coal consumption for all purposes was 1.98 pounds per k. w. h. generated.

10 During a ten day run in September, 1905, the results shown in Table 3 were recorded. The engines averaged 87½% of the pos-

sible running time and on 54% station loading factor[1] the plant consumed 2.04 pounds fuel per k. w. h., or 1.44 pounds per b. h. p. hour. With coal of 13,500 B. t. u. calorific value the efficiency of this plant averages about 13.1%, this rivaling, if not excelling, the largest modern steam power stations. On September 27, the fuel

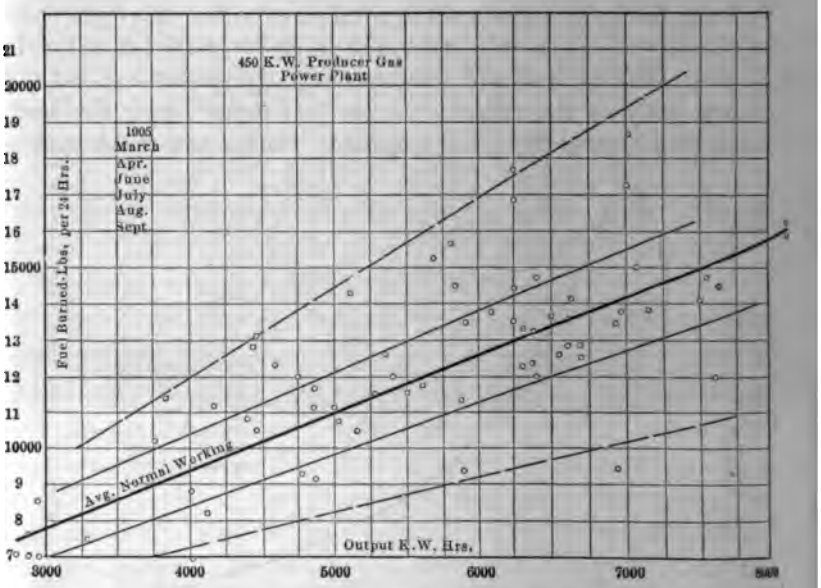


FIG. 5 FULL CONSUMPTION AT VARIOUS OUTPUTS
(GRAPHICAL METHOD OF OBTAINING TRUE AVERAGE)

rate was 1.88 pounds per k. w. h. (or about 1¼ pounds per b. h. p. hour) with 62% loading factor, corresponding to a plant efficiency of over 15%.

11 The author has been deeply interested in the effect of the loading factor of a plant upon its efficiency and commercial duty. An unusually good opportunity arose in analyzing the results of this plant and the approximate relation is presented in Fig. 4. In order to obtain a closer average, the "shotgun" method (Fig. 5) was used, plotting total fuel per day to output. Barring some unusual results

[1] $\text{Loading Factor} = \dfrac{\text{Avg. 24 Hr. Station Load}}{\text{Rated Capacity}}$

$\text{True Load Factor} = \dfrac{\text{Avg. 24 Hr. Load}}{\text{Maximum}}$

occurring in the early days of the plant, the average fuel consumption is approximately a straight line within observed limits. From this the average fuel per k. w. h. may be obtained, Fig. 6, and the relation approximates a rectangular hyperbola within normal ranges of load. The upper convex curve, Fig. 6, expresses the kinetic or absolute efficiency[1] of the station, and it is interesting to observe that this

TABLE 2 TYPICAL LOG

GOULD COUPLER COMPANY

DEPEW, N. Y.

GAS POWER HOUSE DAILY STATEMENT FOR SEPTEMBER 26, 1905

TIME	PRODUCERS IN 1 2 3	ENGINES IN 1 2 3	PUMPS IN 1 2 3	STATION WATT-METERS OUTPUT KW	VOLTS	MAX. AMPERES	REMARKS
A. M. 7	△ △	△ △ △	△ △	1,459,800	230	1000	
8				,300	230	2100	8% over-
9				,300	230	2100	load.
10				,200	230	2000	
11				,300	230	2100	
12		▽ ▽		,300	230	2100	
P. M. 1		△ △		,100	230	2000	
2				,300	230	2100	
3				,200	230	2000	
4				,300	230	2000	
5				,300	230	2000	Full Load
6				,200	230	1800	about
7				,250	230	1700	1950
8				,300	230	1900	amperes
9				,300	230	1900	
10				,300	230	1800	
11				,300	230	1900	
12		▽		,300	230	1900	
A. M. 1		△		,150	230	1100	
2				,300	230	1900	
3				,350	230	1800	
4				,300	230	1800	
5				,300	230	1900	
6	▽ ▽	▽ ▽ ▽	▽ ▽ ▽	,250	230	1700	

Day Engineer, ... Hanley
" Helper, ... Young
" Producer Man, ... Benarak
" " " .... Lea
Night Engineer, ... Lowe
" Helper, ... Runer
" Producer Man, Smith
" " " ——

METER READINGS:

6.00 p. m. 1,462,600
Previous 1,459,700
Output 2,900
Coal, 6,000; Coke, ——
Rate 2.06 lbs. per K. W. H.

6.00 a. m., ... 1,466,000
Previous 1,462,600
Output 3,400
Coal, 6,300; Coke, ——.
Rate, 1.85 lbs. per K. W. H.

[1]Kinetic Efficiency is defined as = $\frac{\text{Thermal Equivalent of work done}}{\text{Heat in coal}}$

small plant normally operates with an efficiency between 12 and 13% average.

TABLE 3 OPERATING DATA

450 K. W. Producer Gas Power Plant

DATE SEPT. '05	ENGINE HOURS RUN	% FULL DAY RUN	OUTPUT K. W. H.	LOAD—K. W. AVG.	LOAD—K. W. RATED	STATION LOADING FACTOR*	FUEL USED	COAL PER K. W. H.	COAL PER B.H.P.HR
20	71	98⅔	4850	202	450	45	11,100	2.29	—
21	65½	91	5275	220	450	49	11,400	2.16	—
22	70	97½	6550	273	450	61	12,700	1.93	—
23	45¾	63½	4025	188	450	41.7	8,800	2.18	—
24 Sun	24	33⅓	2250	187.5	450	41.6	†6,600	†2.93	—
25	70½	98	6400	267	450	59	12,000	1.87	—
26	69¾	97	6300	263	450	58	12,300	1.95	—
27	70½	98	6700	279	450	62	12,600	1.88	—
28	72	100	6700	279	450	62	12,900	1.92	—
29	70½	98	6600	275	450	61	12,900	1.95	—
Avg.	63	87½	5565	243.4	450	54	11,330	2.04	1.44

Westinghouse Vertical 3 Cylinder Engines—Loomis-Pettibone Producers.
*Loading Factor = % continuous generating capacity.
†Includes extra coke used on Sunday for starting new fires.

12 From the above data and the measured efficiency of the gas engine, the efficiency of the producer plant may be roughly estimated. Assuming 50% loading factor, the average plant efficiency is 12%; as the efficiency of the engines is approximately 17% at this load (see Fig. 9), the producer plant operates at an efficiency of slightly above 70%. With higher loading factor—75%, the plant efficiency is 13% average, engines 20% and producers 65%. During an especially good day's run, as on September 27, the efficiencies were as follows: plant 15%, engines 21%, producers 71.5%. These results indicate that the producer plant is, from an everyday operative standpoint, fully as efficient as a high grade boiler plant and frequently more so. It is certainly not more difficult to handle.

13 As to the cost of power the following analysis reveals a total cost of well under one cent per k. w. h., including fixed as well as operating charges. At normal prices, coal[2] costs $2.30 per ton. Assuming average daily outputs of 5000 to 10,000 k. w. h.

[1]Since the above observations were made the plant has been giving much better efficiency, the coal consumption averaging 1.8 per kw. h. with an 85% loading factor. This corresponds to a plant efficiency of over 15.4 at the engine shaft or, 14% at the switchboard. Several runs averaging 1.55 lbs per kw. are recorded, equivalent to a plant efficiency of 17.7% at the shaft, or 16.3% at the switchboard.

[2]Buffalo, Rochester and Pittsburg Bituminous run of mine, 13,500 B. t. u. per pound.

representing the probable minimum and maximum for full working days, and adding the fixed or capital charges amounting to about 9% on $91,650 (or $81,000 excluding the battery), the distribution of cost items is substantially that given on the following page.

APPROXIMATE POWER COSTS

	Minimum	Normal	Maximum
Output—k. w. h. per day	5000	8000	10,000
Fuel—Cents per k. w. h.	0.25	0.22	0.20
Labor—Cents per k. w. h.	0.28	0.17	0.14
[1]Supplies and Repairs (estimated) c. k. w. h.	0.17	0.13	0.11
Operating Costs, c. k. w. h.	0.70	0.52	0.45
Fixed Charges	0.45	0.28	0.22
Total Costs, c. k. w. h.	1.15	0.80	0.67

14 In order to emphasize the effect of loading factor Fig. 7 has been prepared showing the relation of both capital and operating costs to the station loading factor, the former plotted above and the latter below the X axis. Total cost of power is given by the total ordinate. Observe the rapid change in costs on light loading, especially of fixed charges. Coal, on the other hand, remains fairly constant; labor a constant charge, increases rapidly on light loads, and supplies and repairs a variable charge, less rapidly. The importance of loading factor is well brought out by this diagram; *e. g.*, the total cost of power is halved by increasing the loading factor from 24 to 55%. An industrial or railway power plant usually operates on about the latter figure, a moderate sized lighting plant on the former; hence, the danger of indiscriminate comparisons of operating costs in power plant work.

15 Considering that the results above enumerated have been obtained from a comparatively small plant, operating under conditions by no means conducive to the attainment of the highest economies, the Depew plant offers a striking object lesson that should not fail of appreciation among engineers confronted with similar problems; and much credit is due the Gould Company through its consulting engineer,

[1]These charges are estimated owing to absence of more accurate data and the comparatively short time plant has been in operation. Assumed 25% of total power costs at 50% L. F., hence, the estimate is conservative.

It should be noted that were the plant to operate regularly at the lower load factors less labor and supplies would be required and the light load costs would be correspondingly reduced. The curves Fig. 7 are based on full plant in service operating continuously.

Mr. W. E. Winship, and its resident manager, Mr. J. O. Gould, for early appreciation of the advantages of gas power and efficient management of the Depew property. The author begs to acknowledge their courtesy and assistance in placing cost and operating data at his disposal.

Descriptive Section

GROUNDS AND BUILDINGS

16 An excellent location has been chosen for the power plant adjacent to the Lackawanna R. R. main line. In the intervening space is a large semi-circular reservoir, serving the twofold purpose of a cooling pond and reservoir for general fire protection, and incidentally enhancing the attractiveness of the property to no small degree.

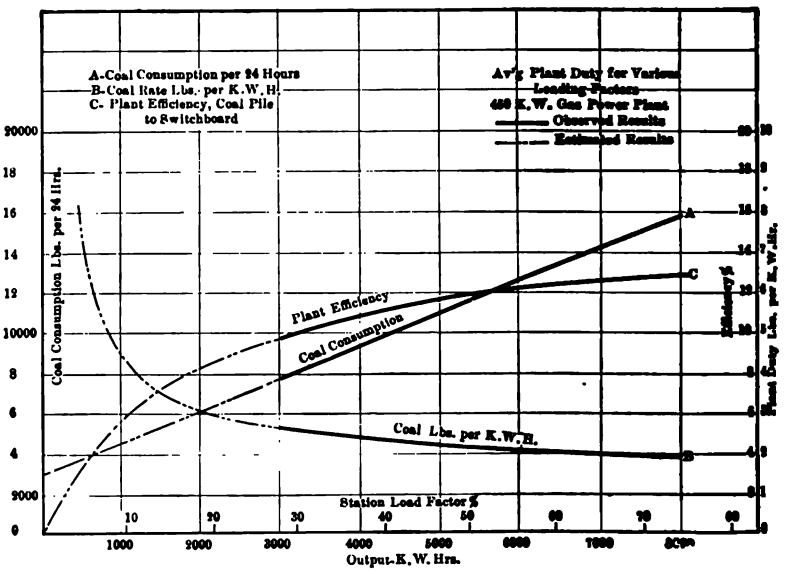


FIG. 6 AVERAGE PLANT DUTY AT VARIOUS LOADING FACTORS

17 For convenience to coal supply the producer house is located several hundred feet in the rear, adjacent to a large metallurgical producer plant serving the steel furnaces. A single coal handling system thus serves both producer equipments. This arrangement of buildings emphasizes the possibilities in gas power work of separating, at any distance, the producer and gas engine parts of a power plant for operative, or other, convenience.

18 Brick, steel and concrete are largely used as building material. In the producer house where the fire hazard is, of course, considerable

no wood at all is employed, walls and roof being constructed of corrugated iron and charging floor of boiler plate. Spacious monitors in both buildings provide the very necessary ventilation and light.

GENERATING PLANT

19 Considerations of operating economy largely influenced the choice of gas engines for this plant where steam coal costs from $2.25 to $2.40 per ton, and gas coal about the same. At this price it was

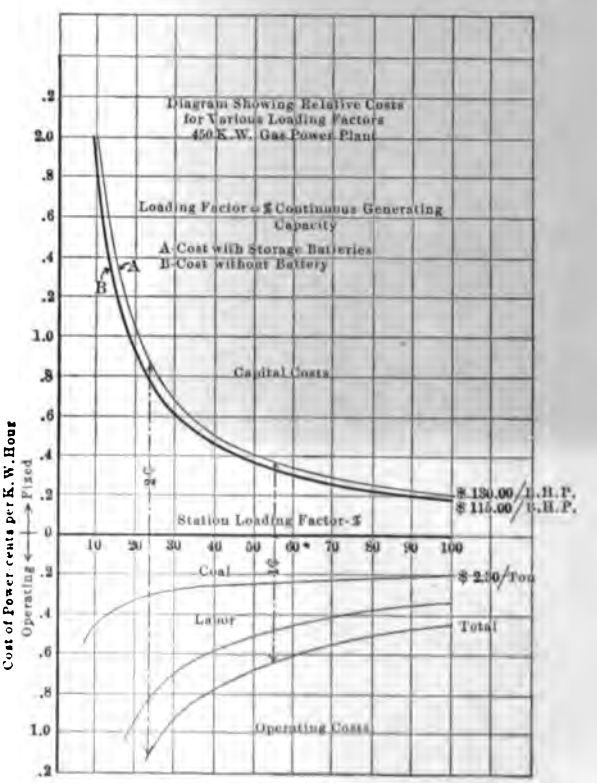


FIG. 7 RELATIVE POWER COSTS AT VARIOUS LOADING FACTORS

estimated that, although the difference between the steam and gas was small on half day working, for a 24 hour day the latter's advantage was decisive.

20 The installation of three units of similar size and identical construction wisely avoided the duplication of parts which two or three sizes of engines would have occasioned. By the use of direct con-

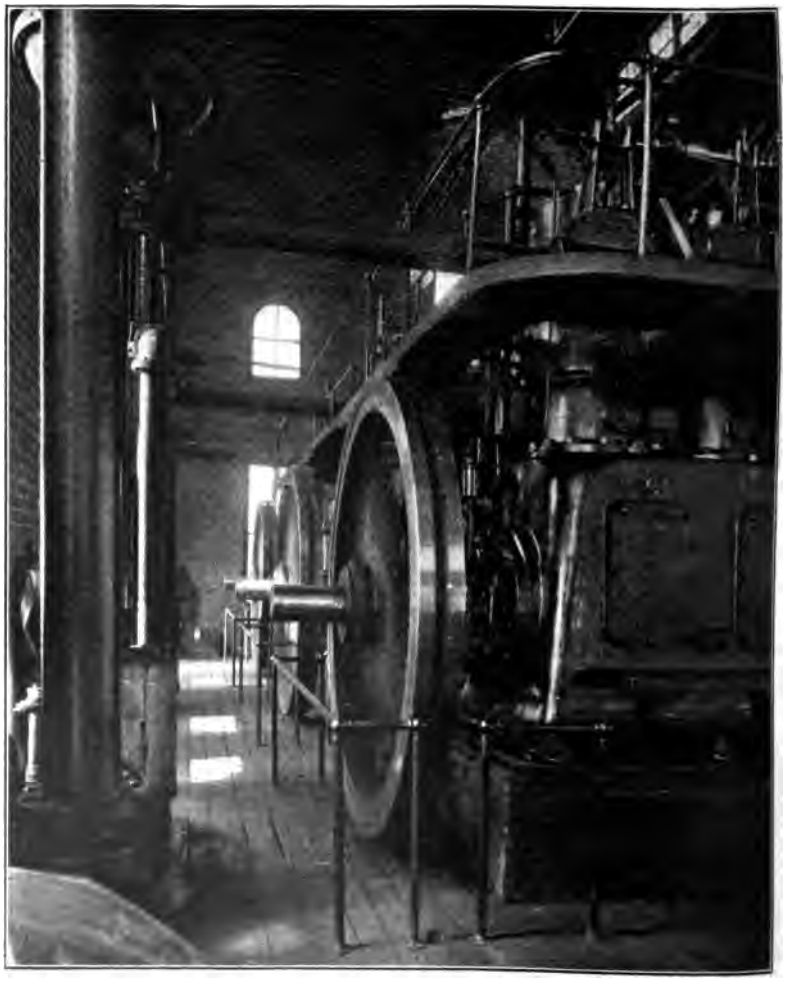


FIG. 8 ENGINE ROOM SHOWING GAS PIPING AND POSITION GAS REGULATORS

nected units a very compact power house arrangement has resulted, the total floor area per kw. being 6.1 square feet, and the net area of each unit with six foot passageways 2.9 square feet per kw.

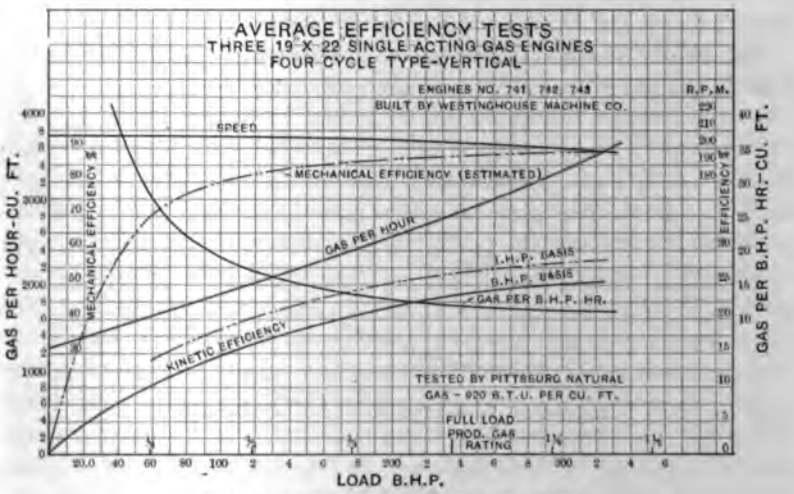


FIG. 9 AVERAGE EFFICIENCY TESTS

TABLE 4 ENGINE EFFICIENCY

AVERAGE OF TESTS

Three 19″ x 22″ Single Acting Four Cycle Gas Engines

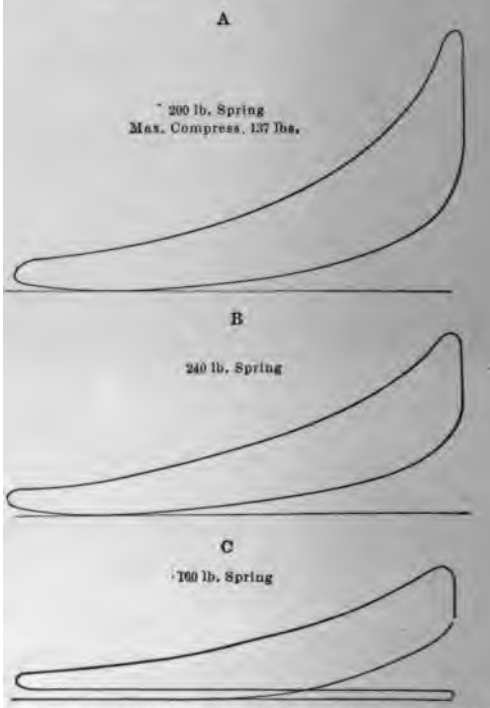
Engines Nos. 741, 742, 743

LOAD	OVER	FULL	HALF	REMARKS
Brake horse power	325.3	239	121.3	By Prony brake.
Speed r. p. m.	198	203	206.3	By counter.
Gas per hour	3,547	2,840	1,985	Corrected to 62° F. 30″ Hg.
Gas per b. h. p. hour...	10.9	11.87	16.36	Corrected gas—no load—1250 ft. per hr.
Heat value gas*	920	920	920	Effective B. t. u. per cu. ft.
B. t. u. per b. h. p. hr....	10,030	10,910	15,050	
Brake kinetic efficiency..	25.37	23.32	16.9	B. h. p. basis.
Mechanical efficiency ...	89	87.5	82.5	Estimated.
Indicated kinetic efficiency.....	28.5	26.7	20.5	I. h. p. basis.
Speed variation-max ...	4.2%			No load speed 206.6.
" " No-full load		1.8%		Average speed.
" " No-half "			0.7%	
Per cent full rating.....	138.4%	101.6%	51.6%	On producer gas.

*Pittsburg Natural Gas—Junker Calorimeter.
Engines rated 235 b. h. p. on 130 B. t. u. Producer Gas.

21 The efficiency of these engines as heat engines is well indicated by the appended results of tests[1] shown in the accompanying Table 4 and diagram Fig. 9. In the latter the upper concave curve represents the gas consumption per b. h. p. under different loads and the convex curve, the kinetic or absolute efficiency.

The ability to convert into useful power over 25% of the effective heat in the gas gives evidence of high efficiency.



FIGS. 10a, 10b AND 10c TYPICAL INDICATOR CARDS
CORRESPONDING TO LOADS IN TABLE 4

22 These engines operate on the four stroke cycle involving constant quality of mixture and throttling governing. The actual proportioning of gas and air is accomplished by two plug valves at the bottom and the top of the mixing chamber, respectively, each with

[1]Made at the builder's works on natural gas which was at that time the only fuel available for testing purposes. As engines for producer gas are usually constructed for somewhat higher compression than those operating on illuminating or natural gas, their efficiency would presumably be slightly better on natural than on producer gas fuel; yet for commercial work a difference of 15 pounds in compression would scarcely be appreciable.

graduated index. These valves may be set by hand at any time to accommodate varying qualities of gas. An automatic diaphragm pressure regulator reduces the pressure of the incoming gas to atmosphere at the engine, Fig. 8.

ENGINE AUXILIARIES

23 A most important factor in the successful operation of the engines is the ignition apparatus. For increased security each igniter plug has two sets of points, each set independently connected. Should one set of points, through any cause, become unfit for use, a small double throw switch may be reversed, thus turning the ignition current through the other points. In addition, three independent sources of current have been provided, all of the apparatus being contained in a central ignition cabinet. For starting, one of two 8-volt storage batteries is used. For running, a small ½ kw. motor generator unit is used delivering 110 volt current to the igniters through incandescent lamps, which furnish a valuable "tell-tale" for "open circuits," "grounded igniters," or "hanging fire" of igniters. These two sets of storage batteries are charged alternately through a bank of lamps from the motor generator or from the main station bus bar one or the other set being always available in an emergency. By means of small double pole switches at the igniter cabinets, throwing over from the low to the high tension system may be instantly accomplished without in the least disturbing the engines. The ignition problem has thus been handled with great care in the provision of six individual combinations of current supply.

24 Starting of the engines is accomplished as usual by compressed air drawn from a pipe connection to a compressed air line in the works or from the relay compressor. Although only 90 to 100 pounds pressure is ordinarily carried; yet the engines may readily be brought up, cold, to full running speed, within 30 to 40 seconds. With higher air pressure available, starting may be accomplished in even less time, as the mixture ignites more readily when quickly compressed, owing to the smaller opportunity for the dissipation of internal heat.

25 Another important part of the plant equipment is the circulating water system for cooling jackets, combustion chambers and exhaust valves. Motor-driven rotary pumps are ideally suited to this work on account of the moderate pressure required—about 25 pounds per square inch. Two of these pumps (one for relay) serve the engine plant, while a third, of the two-stage turbine type, serves the gas producer scrubber in which a higher pressure is desirable. Al-

though each pump is driven by a 15 h. p. motor, the power ordinarily required is considerably less than this, especially in moderate and cold weather when the quantity of water supplied to the engines may be largely reduced by throttling the pump outlets.

COOLING RESERVOIR

26 Previous mention has been made of a cooling pond. This has a normal depth of 10 feet with a total capacity of about 1,000,000 gallons. It is approximately semi-circular in plan and is divided radially into two compartments to separate the comparatively dirty scrubber water from the pure jacket water. All make-up water used at the plant is delivered to the pure water pond through the engine jackets.[1] The excess overflows into the scrubber water pond and thence to the sewer. Cooling water for the engine is drawn from near the bottom through a screen house, while the hot jacket water is returned to the surface of the pond, about 150 feet distant. During the progress of the water from inlet to outlet enough heat is dissipated to the earth and atmosphere to reduce the outlet water to the proper temperature. During periods of extreme heat and humidity when the cooling process is retarded, a larger quantity of water may be sent through the jackets to compensate for the lesser difference in temperature. For this the rotary pumps are well suited. In September, 1905, the following observations were made:

Jacket water entering pond	99.3° fahr.
Surface of water near inlet	78.8° fahr.
Air	73.8° fahr.
Bottom of reservoir near outlet	76.1° fahr.
Surface of reservoir near outlet	77.9° fahr.
Average load on plant	310 kw. = 500 H. P.

Thus on a fair day with practically seven-tenths load on the plant there was a difference in temperature of 1.8° Fahr. in eight feet depth of water, 0.9° Fahr. difference between the temperature of reservoir at intake and outlet, 4.6° Fahr. difference between air and mean reservoir temperature and 23.2° Fahr. total cooling.[2] Apparently considerable cooling took place through the transmission of heat through the bottom of the reservoir.

[1] It is of interest that nearly all of this "make-up" water is supplied from roof drainage. City water being comparatively expensive (10–15 c. per 1000 gallons) and this utilization of roofage insures an important economy. The pond also supplies feed water for some steam boilers.

[2] As there was no overflow from the power pond at the time this cooling was effected from about 7300 sq. ft. of exposed water surface

PIPING

27 Some trouble has been experienced with the gas gates, due apparently to cumulative deposits of carbon, and frequently it becomes impossible to seat the valves tight. In work of this class it would seem that a parallel seated quick closing gate would be best suited, being self-cleaning, and the gas could be cut off almost instantly in case of emergency.

28 The engine exhausts all discharge into a cast iron header running beneath the floor to a concrete exhaust well outside, serving as a muffler. Unfortunately, it is impossible to cool these exhausts by water sprays on account of the large amount of SO_2 in the gas. If water were used, as is the practice with natural gas, the piping would soon be destroyed by corrosion. As some 30% of the total heat value of the gas is lost in the exhaust, radiation is a somewhat disagreeable feature, especially in warm weather. This trouble may, however, be obviated by enclosing the piping in a concentric sheet metal casing through which rapid circulation may be maintained from basement to ventilators in the roof. It is also possible that a reinforced concrete duct might be employed for exhaust piping, molded in sections, cemented in position and encased in sheet steel. If rigidly supported this material should easily withstand both the heat and corrosive action of the exhaust vapors when water cooled in the usual manner.

29 The muffler well is, to be sure, a common arrangement in gas power plants, but most certainly could be improved upon. First, the noxious products of combustion rising from the pit, although located in the open, are driven directly into the engine room during certain prevailing winds to the great discomfort of the operators. Second, if the exhaust pit is carried to any considerable distance from the power house, a serious back pressure is imposed on the engines owing to the friction of the high pressure exhausts on the internal surface of the main. Usually the well is located close to the building with a short standpipe. This outlet is almost invariably too small, resulting again in serious back pressure from throttling. And it usually occurs that sooner or later the structure is dismantled by sudden pressures due to delayed combustion or other causes. A more logical arrangement would seem to be as follows: (1) A brick or concrete exhaust well of large dimensions built next to the power house foundation wall and loosely filled with large broken rock, (2) a brick stack extending to the roof and built into the building structure integral with pilasters thus taking advantage of the reinforcement offered by the steel skeleton of the building, (3) simple sheet steel flap doors or louvres inserted in

the roof of the exhaust pit and at two or three points in the chimney to relieve occasional local pressures. In this manner the noxious gases are easily taken care of by a flue of cheap construction, agreeable appearance, and ample capacity for any contingency.

30 Water cooling piping is simple, a manifold supplying all three cylinder jackets in parallel. Water enters at the bottom of the jacket, emerging from the top. A small pipe loop at the discharge end of the upper manifold with vent cock at the top to break the vacuum serves to prevent the syphoning effect which under certain conditions might pull all the water out of the jackets, leaving nothing but steam. This vent is useful as a tell-tale showing stoppage of jacket water supply.

31 In cooling the exhaust valves a fairly constant supply is desir-

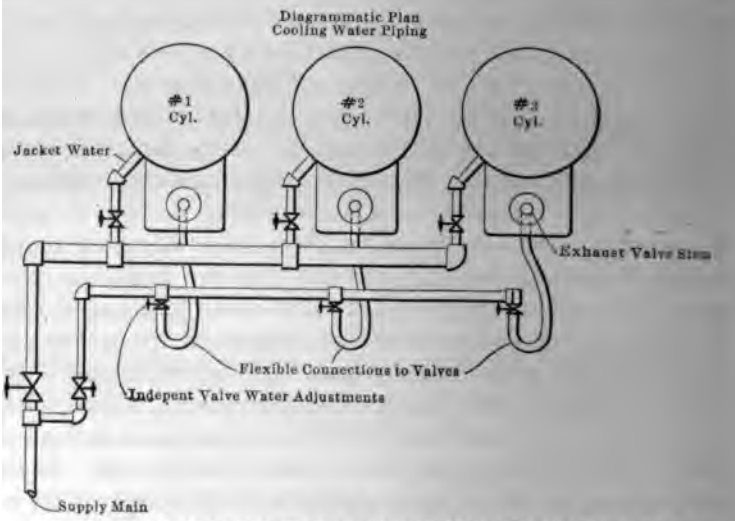


FIG. 11 PLAN COOLING WATER PIPING FOR CYLINDERS AND EXHAUST VALVES

able, irrespective of the load. The arrangement shown in the sketch, Fig. 11, is therefore employed by which the jacket water may be throttled as much as desirable, while constant head is maintained at the exhaust valves.

OPERATION OF ENGINES

32 Four men, two to a shift, operate the generating plant, the oilers and the two engineers, being formerly steam engine operators. The personal attitude of the chief engineer toward the gas engine plant well refutes the frequent argument that gas engines require more skilled operators than steam engines; the plant not only requires

less actual manual labor to keep in running order, but it is fully as responsive to good handling as a steam plant. All things considered, he "would regret to go back to steam." The fact that the engines are often left in charge of, and operated by, the oilers illustrates the point in view.

33 While the producer is undergoing renovation on Sundays, the engines are also inspected in rotation, mixing valves flushed down with gasolene to remove lampblack deposits (likewise cylinders, now and then to keep the packing rings free), valves are ground in and igniters replaced when necessary, jacket deposits cleaned out when obstructed to any extent, and the engines generally adjusted. Reducing valves are also cleaned, at intervals, from carbon deposits. Practically the only trouble experienced thus far has been the occasional cutting of an exhaust valve, presumably due to cumulative carbon deposits on the valve seats. The lampblack has also occasioned some difficulty in lubricating valve stems. Igniters, of course, wear down gradually, but extras are always kept on hand and repointed as fast as necessary. Usually one igniter will last from six to nine months without repointing. Since commencing normal operation engine repairs have been confined to these two items and are comparatively light considering the conditions of operation. Very little trouble has been experienced with lubrication, as the main working parts are automatically supplied by the splashing of oil. All oil used in outer bearings returns to the crank case to make up that lost through evaporation. When the oil reaches too high a level the excess is drawn off, filtered and used over in the bearings.

34 In starting and stopping the engines the attendants have acquired so much skill that the barring lever is seldom used. By manipulating the air valves just as the engine comes to rest it is not difficult to bring the air cams in starting position so that no time need be lost in barring the engine around to the position for starting.

PRODUCER PLANT

35 A notable feature of the producer plant is that it is capable of gasifying bituminous coals without making quantities of tar. The process is intermittent, embodying the now more or less well known system of passing the green hydrocarbon distillates through a secondary fire bed which has previously been brought up to the proper temperature by blasting with air. Since the plant was started, a fair grade of soft coal (B. R. & P. run of mine) has been used, averaging about 13,500 B. t. u. per pound. Although this coal presumably contains 35% of volatile, tar destruction in the producers is complete,

but at the same time a considerable quantity of lampblack has resulted which has made it necessary to devise special means to handle this by-product. No attempt has been made to market it, as some is used in the preparation of paints for castings, etc.

36 Straight producer gas is not made directly, but water gas and air gas are made at alternate intervals of varying duration according to richness of the gas desired. In metallurgical plants the two gaseous products of the system are often handled separately, the water gas being used for heating furnaces on account of its high flame temperature and the blast gas in gas engines for power purposes. And it is an interesting fact that, although this blast gas would be absolutely unfit for any other use on account of its comparatively low calorific value—from 80 to 90 B. t. u. per cu. ft.—yet it is quite suitable for gas engine work, in that it is not at all snappy (as is water gas) and, therefore, permits of higher compression. At Depew the two gases are mixed in a single holder in the proportion generated.

37 In this system two producers constitute a unit. Usually it is desirable to have a separate unit on hand for relay purposes. Here this was especially necessary in order to provide an opportunity for freeing the producer from clinker formed during the week's run. At Depew a novel arrangement was first employed, in the form of a clover leaf with three producers united at top and bottom by T pipe connection with the necessary water cooled valves. It was then possible to renew one producer fire per week in rotation, and at the same time save the cost of a fourth producer to complete the duplicate unit. Through no fault of this arrangement, however, it was not an entire success, owing to the difficulty in preventing the leakage of water gas into the idle producer through the valves. This difficulty has now been overcome and a complete relay plant, including scrubbing equipment, is provided in the adjoining producer building with sensibly better results than before.

PRODUCER AUXILIARIES

38 A feature of the system is that all steam required is generated entirely from the sensible heat of the gases coming from the producers which would otherwise be wasted in cooling water.[1] With the high "heats" necessary in the intermittent process, this represents an important saving. The boiler, however, requires weekly cleaning.

[1]This condition however obtains only when the plant is heavily loaded. Running light it would be difficult to make sufficient steam to operate the producer auxiliaries. An air auxiliary boiler would have to be drawn upon.

39 The proper cleaning of the gas is a difficult problem, owing to the fact that lampblack does not easily adhere to a wetted surface as does ordinary cinder dust. In this plant the gas first passes upward through a wet scrubber containing several tiers of small coke constantly wetted down by water sprays. A thin layer of dry excelsior is also used in the top tiers. Emerging from the wet scrubber, the gas enters two large dry scrubbers filled with several tiers of excelsior and piped up in parallel so that the velocity of the gas is not only reduced, but also the amount of gas handled by each drier. Finally, an engine driven Root's exhauster delivers the gas to the holder.

40 The various valve movements are handled mechanically by rack gears with operating wheels conveniently placed on the level of the operating floor.

PRODUCER OPERATION

41 The present method of operating the producer plant requires an air gas run of 10 to 15 minutes, according to the demand for gas at the power plant, and a water gas run from one-half to three-quarters of a minute, the resulting mixture being well suited to power work.

42 Frequent testing of the quality of the gas made is not now practiced on account of its uniformity under the present operating condition. The holder, of course, greatly assists in insuring uniform gas at the engines. At the same time it provides sufficient capacity for operating one unit at full load for about three-quarters of an hour; the full plant in inversely proportionate time. Storage capacity is particularly valuable when a new fire is being put into service. This is usually done during the noon hour when the load is light, so that a lowering of the heat value of the gas is relatively unimportant.

43 In ordinary operation it is a simple matter to observe the quality of gas by means of two sampling flames always in view of the operators. One consumes gas from the holder; the other consumes freshly made gases as they leave the dry scrubber. Any irregularities may then be readily detected. Calorimeter tests show the gas as made at the present time to average slightly above 100 B. t. u. per cu. ft. (see Table 5). This comparatively low heat value is, of course, due to the preponderating period of blasting. With the rate of water gas mixing practically fixed, the only variable factor to compensate for varying demands for gas is the rate of blasting; hence, there is a long and subdued air gas run with a rapid but short run on water gas. During the second test (Table 5) the gas consumption was observed to be about 1100 cu. ft. per minute at a load of 395 kw. This is

equivalent to 167 cu. ft. per k. w. h. at seven-eighths load on the generating units, and represents approximately a duty of 16,700 B. t. u. per k. w. h., or a little over 11,000 B. t. u. per b. h. p. hour.

44 Coal consumption is determined by direct weighing in the producer house. Each shift weighs up enough coal at the start to run the plant through twelve hours; should there be a surplus at the end, it is weighed back and charged to the next shift, thus making each shift responsible for all fuel used during their run.

45 The entire producer plant is operated throughout the week by four men, two to a shift, with some additional labor on Sundays for cleaning. All the attendants were unskilled foreigners before taking up the producer work. During a half day shut down of the plant on Sundays, all renovating of the producer equipment is done; boiler tubes are cleaned, wet scrubber washed down, the excelsior in the dry scrubbers taken out and shaken free from lampblack, gas mains

TABLE 5 CHARACTERISTICS OF POWER GAS

TYPICAL ANALYSIS

Date, June, 1905	20th	21st	23d
Number of hours test	3	10	10
Intervals of tests (minutes)	15	15	15
Minimum calorific value	98	91	91
Maximum " "	113	110	104
Average calorific value	105	100	100
Maximum variation from avg.	7½%	10%	9%

DATE	H	CO	CH_4	O	CO_2	N
Sept. 9, 1905	9.50	21.0	1.9	0.6	6.5	60.9
Sept. 12, 1905	10.13	22.8	2.2	0.4	5.6	58.9

flushed out and a new fire started in the idle producer. At the same time, another producer is taken out of service, fires are drawn, and during the week, after it has had an opportunity to cool off, the hard clinker, which adheres to the lining, is broken off. For the starting layer of a new fire bed, coke is used to the extent of some 3000 pounds per producer, a sufficient quantity to affect the coal consumption of the succeeding day. If allowed to form to any extent, clinker constitutes a frequent source of trouble in operating the plant, and it is important that the selection of coal be made with this in view. With fires fairly free from clinker the suction required for blasting may be only eight to ten inches of water, but with fires badly clinkered it may run up to 25 inches. With 10 to 15 inches drop in the scrubbers, this imposes from 30 to 40 inches suction on the exhauster, thus largely increasing its steam consumption.

DISCUSSION

MR. W. D. ENNIS There is in this paper what would seem to be a slight discrepancy. In Table 1, the power building is stated to be 45 x 61 feet inside. This would make the area 2745 square feet and would give 6.1 square feet of area per kilowatt of capacity, exclusive (apparently) of the producer house. In the second column of this table, the power plant area is given as 7300 square feet, and that of the producer house as 7500 square feet. On this basis, the total square feet per kilowatt of capacity would be 32.9. The new turbine power plant of the West Jersey & Seashore Railroad covers only 2.13 square feet of ground per kilowatt of capacity. The Summer-lane Station at Manchester, England, recently completed, uses 2.45 square feet per kilowatt, the plant containing both reciprocating and turbine engines. These are both much larger plants, however, than that which Mr. Bibbins describes.

2 Regarding the use of the term "loading factor," we need a name for this ratio, but would not "capacity factor" be better? We sometimes have occasion to consider also the relation of peak load to rated capacity. I would suggest, therefore:

Load factor = average load : peak load.
Capacity factor = average load : rated capacity.
Peak factor = peak load : rated capacity.
Load factor × peak factor = capacity factor.

THE AUTHOR Reference was made in the foregoing paper to the effect that more recent data indicated considerable improvement in the operating efficiency of the Gould plant over that first reported. This is due somewhat to more careful operation but largely to the increased loading of the plant. The month of June, 1906, may be taken as a typical example of these latter results:

Length of run (daily including Sundays)				24 hours.
Daily output	max. 9700	min. 1600	avg.	7500 kw.h.
Station loading factor	max. 90%	min. 15%	avg.	69.5%
Net coal per kw.h.....	max. 1.97	min. 1.53	avg.	1.78 lbs.
Extra fuel for building new fires (6%+)				0.108 lbs.
Total fuel per kw.h.				1.88 lbs.
Plant efficiency (running) ..	max. 16.6	min. 12.9%	avg.	14.5%
Plant efficiency including extra fuel for new fires.....				13.4%

2 The accompanying curves summarize this data as well as that presented in the foregoing paper. Observations now cover a range of loading from 25 to 90 per cent of the station capacity. A notice-

able effect of the higher loading is a departure from the straight line referred to in the paper as representing the relation between total coal consumed and output. There is a noticeable bend in this total coal line indicating a higher efficiency of working on the higher loadings. This point would not be apparent from the fuel rate curve. It results in a constantly increasing plant efficiency. It should be noted that these curves represent averages as determined by the graphical method previously described. The results are as follows:

Station loading factor	50%	75%	100%
Coal per kw.h.	2.1	1.85	1.68 lbs.
Plant efficiency	11.7	13.6	15.2%

All standby losses as well as mechanical and electrical losses are here taken into account, so that the gross efficiency of conversion of coal into measured electricity is represented by the figures given, 15 per cent at full load.

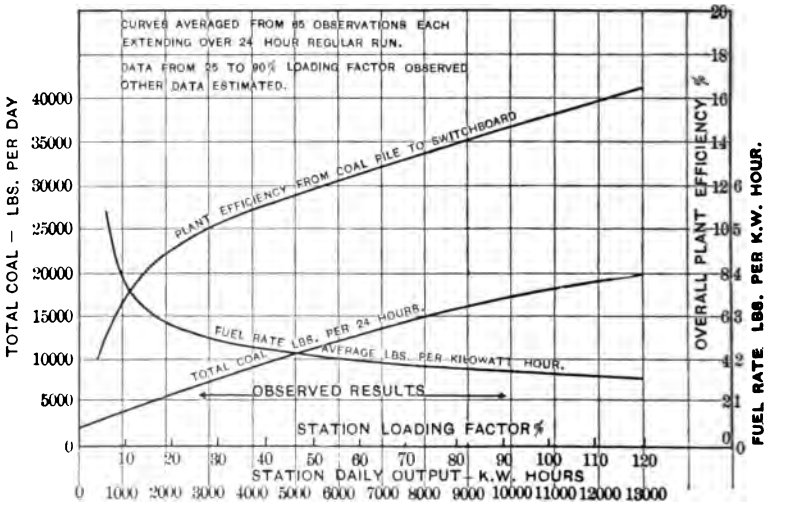


FIG. 1 SUMMARY OF OPERATING RESULTS, GOULD COUPLER CO., DEPEW, N. Y. PRODUCER GAS PLANT

3 In the original paper the cost item of repairs could not be definitely given, and it was necessary to estimate this quantity owing to the absence of separate data. This estimate checks closely with later records for 1906 which, however, show a rather high labor cost. This is due to the fact that a certain number of men are required to operate a plant of this character regardless of its capacity up to a certain point. In this particular instance it is safe to say that the

same force could readily handle double the plant capacity. Assuming the station loading factor to be about 70 per cent, a distribution of cost items is approximately as follows:

	PER CENT TOTAL COST	PER CENT OPERATING COST
Fuel	27.4	38.4
Wages	29.5	41.4
Supplies	5.8	8.2
Repairs	8.6	12.0
Operating	71.2	100.0
Fixed	28.8	
Total cost	100.0 = 93c. per kw.h. = $60 per e.h.p. a year	

4 The apparent discrepancy which Mr. Ennis has observed in the relative floor space of the Gould power plant is due to his misinterpretation of the data in Table 1. In one case the area of the power house is given: in the other, that of the two compartments of the cooling pond outside. The relative floor space of the former is as stated—6.2 feet per kilowatt.

5 The term "loading factor" may very possibly be misleading, but was used in the absence of a standardized expression. "Load factor" in its true sense is definitely restricted by long usage to a central station load which is continuous and practically devoid of violent fluctuations. There is, therefore, little chance for misapplication. But with the fluctuation load of an industrial plant, such as that under description, the term is decidedly indefinite with frequent swings, 50 per cent or more above the average carried at the time, it is very doubtful if the quantity

$$\frac{\text{Average load}}{\text{(Instantaneous) Maximum}}$$

would represent load factor as accurately as

$$\frac{\text{Average load}}{\text{(Steady) Maximum}}$$

The latter, however, is somewhat of an anomaly.

6 It would seem to the author that a clear distinction is necessary between terms relating to the outside business or connected load of a

central station and those concerned only in the relative load of individual units or the station as a whole. The former is external to the power plant, the latter internal, and most closely involving operating efficiency, and as rated generating capacity is the usual reference point in expressions of efficiency the term "loading factor" was chosen as the most appropriate: *i.e.*,

$$\text{Station loading factor} = \frac{\text{Average station load}}{\text{Total rated capacity}}$$

Applied to an individual generating unit, this is equivalent to the "per cent full load rating," which may readily be found as the ratio of the integrated areas of load curve and engine capacity curve respectively. As the terms "loading" and "capacity" are so dissimilar in meaning, the author still considers the former preferable. "Capacity factor" would seem more applicable as an expression indicating the excess generating capacity available above the maximum load carried, *i.e.*, what Mr. Ennis designates by still another term "peak factor," or the ratio of maximum load to rated capacity.

7 The most useful expression from the standpoint of operating efficiency is the ratio

$$\text{Loading factor} = \frac{\text{Average running load}}{\text{Rated capacity in operation}}$$

which is the true "loading factor" for any length of run of whatever duration. Excess plant capacity does not effect the validity of this term, but it is taken into account in "station loading factor." The former applies with equal accuracy to a 10 hour or 24 hour continuous load; but the latter covers losses of standby as well as running periods. In the former we have an exact check of the proportioning of plant capacity to load; in the latter, a measure of the duty imposed upon the equipment, while the original term "load factor" indicates the possibility of increasing the output and revenue during lightly loaded periods of the day.

8 In connection with this subject of power costs, the author cannot resist the opportunity for earnestly recommending the keeping of daily records, in which an astonishing number of plants of very respectable size are at fault. In no manner can irregular and faulty operation be more readily detected than by reference to the fuel scales, water meter, and watt meter on the daily log. Very little time is required to make these simple observations, and in the making much is learned by a wide-awake operator, who takes proportionately

greater interest and pride in the plant under his charge. Few men are insensible to opportunities for self improvement and here is an opportunity that has been much neglected in the past and is even today. The mere taking of meter readings is not the essential point but rather the interpretation of them by the engineer himself.

9 From this neglect arises the difficulty of obtaining economic data often desired for comparative purposes. Every power plant manager seems to use a different system or basis of calculations with the inevitable results that data of this character are very generally misleading unless one is completely familiar with the surrounding circumstances. It is the author's belief that much good might be done in the formulation, by some engineering body, of a definite scheme or code for the determination of power costs upon a broadly comparable basis somewhat similar to that in force in Great Britian by legislative enactment. As fuel becomes dearer in America this matter will receive proportionately greater and greater attention.

No. 1127

STEAM PLANT OF THE WHITE MOTOR CAR

By R. C. CARPENTER, ITHACA, N. Y.
Member of the Society

1 The steam plant of the White Motor Car is an example of what can be accomplished on a small scale in the use of steam of high pressure and with a high degree of superheat in the steam engine and is consequently of interest to the mechanical engineer irrespective of its special application for the propulsion of motor cars. I take pleasure in presenting a description of this plant and also the results of a series of tests which I believe will prove of considerable interest to all engineers who are studying the question of the use of steam at high temperatures and pressures.

2 The White steam system was designed by R. H. White and has been successfully applied by the White Sewing Machine Company, during the last six years, to several thousand motor cars; its essential and novel features are found principally in connection with the steam generator or boiler which is adapted to produce steam of high pressure and high temperature. The system is also of interest in the details of construction of its engine and in the means for automatically controlling the quantity, temperature and pressure of the steam produced.

3 It is a well recognized fact that the efficiency of a steam plant is increased by the use of steam at high temperatures and pressures and there are numerous tests on record which bear testimony to this fact. The development of the art of producing and using steam of high pressure and of a high superheat has been slow although probably continuous. So far as I can learn from correspondence, no boilers or engines exceeding 100 h. p. in capacity which are adapted to produce and use steam exceeding 300 lbs. pressure, and 300 degrees superheat are built in this country at the present time. At least I

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have been unable to find makers of both boilers and engines who could meet that kind of a demand. My own experience leads me to believe that the practical limit of pressure in steam plants of any considerable size in this country at the present time, taking into account boilers, engines, piping and valves, is not much above 200 lbs. per square inch. There are but few engines adapted for using steam with a superheat exceeding 200° F. This condition is doubtless accounted for by the existence of numerous practical difficulties, many of which relate to piping and valves and to the materials of construction which are now in ordinary use. There are also, no doubt, com-

FIG. 1 THE WHITE GENERATOR

SHOWING ALSO THE BURNER, VAPORIZER, PILOT LIGHT AND GASOLENE CONNECTIONS WITH EXTERNAL CASING REMOVED

mercial difficulties of importance connected with the cost of manufacture and with the demand. I am of the opinion, however, that if the steam engine is to maintain its position as the principal power producing machine in competition with the internal combustion engine, the steam pressure and degree of superheat must be very largely increased over that in use at the present time. To meet these conditions there will be required many changes in design and construction of both engine and boiler, which will probably require a long period of development to perfect.

4 The steam turbine, which is already in extensive and successful use, is well adapted for steam of high pressure and a high degree of

superheat, without change of design or construction, and will doubtless be used in a continually increasing proportion for producing power as the art of producing steam of high pressure and a high degree of superheat is developed.

THE GENERATOR

5 The steam generator or boiler of the White system is a series of horizontal coils connected so as to form a continuous tube through which all the water fed to the boiler and all the steam discharged from the boiler must pass. It is not provided with any reservoir either for water or steam. A perspective view of the boiler, as used in the 1906 car, is shown in Fig. 1 with the external casing removed. Its

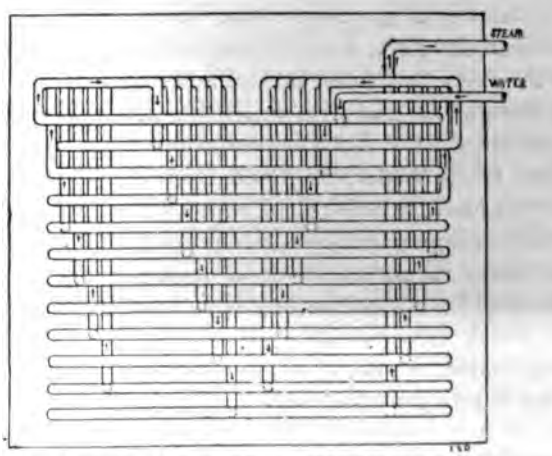


FIG. 2 DIAGRAM OF GENERATOR CIRCULATION

essential distinctive feature from every other boiler is due to the fact that the water is kept at the top and the steam at the bottom; it differs from all types of stationary boilers by the absence of a reservoir for steam. The construction of the boiler for the 18 brake horsepower engine, which was used in the 1906 cars, is essentially as follows, and is typical of all sizes: eleven helical coils of drawn steel tubing are joined in series and connected as shown in the diagram, Fig. 2, so as to produce a system of circulation of such a character that the water or steam, in order to pass from one coil to that next below, must rise to a level above the top coil before it can pass down again. Fig. 1 shows the external view of the connections referred to, which pass from the external circumference of the coil upward to a point above the level of the top coil and thence downward in the central

space, where it joins the coil of a lower level. Tubing having a nominal internal diameter of $\frac{3}{8}$ inch was used in the boilers of 1904–1905 and 1906, and of $\frac{1}{2}$ inch in the new boiler recently built for the 1907 car.[1] The joints connecting the various coils are, it is noted, located in an accessible position. This construction makes it possible to maintain water in the upper portion of the boiler and steam in the lower. It prevents the water from descending by gravity and renders the circulation through the generator dependent upon the action of the pumps which supply the boiler with water. The general direction of circulation of the water and steam is the reverse of that of the products of combustion.

6 The White boiler has frequently been classified as a flash or semi-flash boiler; whether this classification is correct or not depends upon the definition of the term "flash boiler." In the flash boiler, as I understand the term, water is suddenly converted into steam by contact with a very hot metal surface and in the operation of such a boiler the metallic surface with which the steam is brought in contact is maintained at a much higher temperature than that of the steam. The White boiler, as noted from the description, always contains a considerable amount of water which is forced downward and over the heating surfaces at a rate proportional to the demand for steam, and under its normal mode of operation it is doubtful if the metallic surfaces have much or any higher temperature than that of the steam which they contain. The name "continuous flow" or "single tube boiler" would, it seems to me, better describe the class to which the White generator belongs than the term "flash."

STRENGTH

7 The construction of the boiler has been shown and described, from which it is seen that the diameter of each pressure element is small and consequently of great strength and not likely to be strained to any high percentage of its ultimate strength by any pressure which could be produced under ordinary conditions.[2] The high working pressure gives great power to the engine and explains the great success of the car in climbing high hills and in passing over unusually bad roads. A safety valve, not shown in the drawing, is attached which may be set at any desired pressure but is usually

[1] The actual dimensions of tubing used in the White boiler are as follows: E and F boiler (1905–06), internal diameter 0.372 inch, outside diameter 0.535 inch; G boiler (1907), internal diameter 0.540 inch, outside diameter 0.72 inch.

[2] The strength of the fittings at the point of leakage for the tubing I found to vary from 7000 to 18,000 lbs. per square inch. See Appendix.

set to blow off at from 1000 to 1200 lbs. per square inch. Because of the small quantity of water and steam present in the boiler no serious damage is probable to person or property, even should the boiler tube be accidentally split or ruptured, as the effect would be simply that of allowing the steam to escape gradually without producing any disastrous results, and even this accident has been extremely rare. Considering the fact that thousands of these steam generators are in use, in the charge of men who have had practically no experience in the operation of steam plants, the results as to freedom from accident are remarkable, and indicate that the apparatus is, from the standpoint of safety, not open to criticism.

8 I have tried to get data respecting the amount of deposit of scale in the tube of the White boiler, due to its continued use, but without any very great degree of success. Investigation indicates that there has been very little practical difficulty due to this deposit and the makers report only a few instances which have come to their knowledge of any trouble from this cause. The velocity of discharge of steam through the single tube of the boiler is great and it is believed has been sufficient to remove the deposits in nearly every case. In the boiler, of which the results of the test are given later, as much as 488 lbs. of steam were produced per hour by the one-half inch tube. Without taking into account the extra volume produced by superheat, the calculated velocity approximates 400 ft. per second through the tube. Because of increased volume due to the high degree of superheat the actual velocity approximates one-third more.

9 For the actual operation of the White boiler on the motor car, water is taken from a reservoir which is supplied in great part with water condensed in an air surface condenser. The condenser is located at the front of the car and receives the exhaust from the engine which contains an appreciable amount of cylinder oil. A large proportion of this oil remains in the water tank and is discharged when convenient, but at times quite a considerable amount is forced through the boiler. So far as the makers have been able to ascertain, no injurious effects have been caused by this practice and as a consequence they have made no attempts to introduce a separator for removing this oil.

THE BURNER AND FUEL CONTROL

10 The furnace or burner which is employed with the steam generator for use on motor car is shown at *P*, Fig. 1, located beneath the boiler and adapted for the burning of gasoline vapor. The figure also shows the various means of automatic control of fuel and water

which are employed with the [illegible]rator. While burners of other types adapted for other fuels than g[illegible]solene can, and doubtless will, be used when conditions demand it, t[illegible]e gasolene burner employed has proved very efficient. In the burning of gasolene, a vapor must first be produced by heat or other means which must be mixed with air previous to the combustion in order to give perfect results and high efficiency; for this reason all [illegible]solene burners are provided with means for vaporizing the gasolene before it is fed to the furnace, which usually consists of means for heating termed a *vaporizer*, as is shown at *O*, Fig. 1. The burner consists of a cast iron grate with slotted openings shown at *P* with a sheet metal chamber underneath, closed except where pipes enter for admission of air as shown at *M*. In the 1905 car, the air pipes were directed radially into the chamber below the burner. In the 1906 car the air pipes direct the entering air

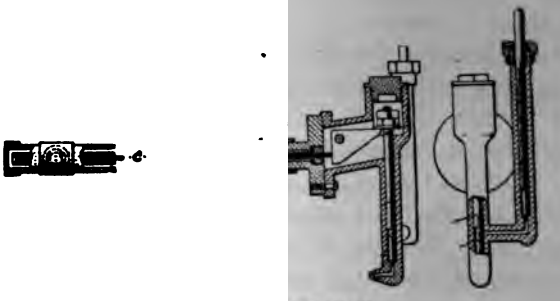


FIG. 3 THERMOSTAT

tangentially, as shown in Fig. 1. The change in the direction of the air pipes has resulted in a decided reduction of noise and an increase of capacity and efficiency of the burner. For the 1906 car the air pipe is supplied with a regulating valve. The gasolene is supplied through a pipe and flows past a valve *D* which is operated by a thermostat; it then flows into the vaporizer *O*, where it is heated; thence it flows to the center of the air pipe *M*.

11 The thermostat shown at *Y* in Fig. 1, and in detail in Fig. 3, consists of a casing *B*, enclosing a rod *C*, inserted into the steam pipe so as to be in contact with the steam on its passage from the boiler to the engine. The expansion controls the gasolene value at *D*, Fig. 1, and at *F*, Fig. 3. The thermostat is ordinarily adjusted so that the oil supply valve will remain open until the temperature of the steam rises to about 800° F. In order to light and relight the main burner when

necessary, a small gasolene flame called a pilot flame, shown at *C*, Fig. 1, is kept burning constantly during the time the vehicle is in use. The valves for the hand control of the gasolene supply are shown at *L*, Fig. 1. In the operation of the burner the gasolene is discharged with considerable velocity and while in a vaporized condition into the air pipe *M*, Fig. 1, and by this operation draws in a sufficient amount of air for supporting combustion, which is mixed with the gasolene vapor and burns with a hot flame on top of the cast iron grating.

FEED WATER CONTROL

12 For the purposes of use on the motor car it is also desirable to have an automatic control of the supply of water; this is obtained in the White motor car by means of a pump which is directly connected

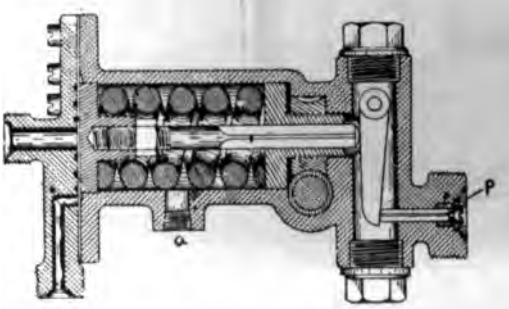


FIG. 4 WATER REGULATOR

to the engine and which may deliver water either directly into the boiler or into the source of supply, depending upon the opening of a valve controlled by the steam pressure acting against a spring, as shown in section in Fig. 4. If the pressure rises above 400 lbs. or to any desired amount, the valve *P* is opened so as to return the water through the opening *Q* to the source of supply. If, on the other hand, the pressure is below the required amount, the valve is closed by the tension of the spring and is forced by the pump into the boiler.

13 It is noted by the illustration, Fig. 1, that no water gage is supplied to the boiler and from the descripiton of its operation it is seen that none is necessary.

14 The water circulating system is shown in Fig. 5, the generator being at the extreme right hand, the condenser at the extreme left,

with the various pumps and pipe connections intermediate. The water tank or reservoir is shown at *27A*, the two feed pumps are at *23*. These pumps are mechanically connected to the engine and take water from the reservoir *27A*, and deliver this water either into the generator or into the source of supply, depending upon whether the by-pass valves, with which both deliveries are provided, are open or closed. The by-pass of one pump is controlled by hand by the value *28A*, and of the other pump by the water regulator which is located at *9* and has been fully described. A hand pump is provided at *17A*, which may be used to fill the generator when the engine is not running. The water is taken from the lower portion of the condenser through the

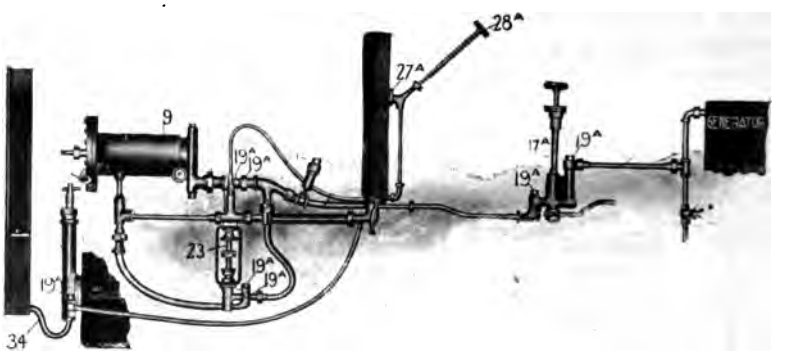


FIG. 5 WATER CIRCULATION SYSTEM

pipe *34*, by vacuum air pump *19A*, and delivered to the reservoir. This pump is also kept in continuous operation by direct connection to the engine.

OPERATING CONDITIONS

15 In the operation of the plant, as applied to a steam car and provided with the automatic devices as described, the fuel and water are supplied as the demand for steam requires, with scarcely any attention on the part of the operator. Thus, for instance, if the steam pressure becomes excessive, the water supply is closed off by the water regulator, Fig. 4, which immediately causes the pressure to drop. If the temperature of the steam becomes excessive, which would soon be the case if the water supply were turned off, the fuel supply is cut off by the thermostat, Fig. 3, which soon reduces the temperature to the normal amount. On the other hand, if there is an excessive amount of steam drawn off, the pressure and tempera-

ture would change in the reverse direction, which would cause the automatic devices to turn on a supply of fuel and water to meet the demand.

16 For the purposes of meeting an extraordinary demand for power which sometimes happens in ascending a long hill, an auxiliary pump already referred to is kept in constant operation by the engine, the discharge of which can be made to go either into the boiler or into the source of supply by opening or closing a valve by hand, which is located convenient to the operator. It is noted from this description

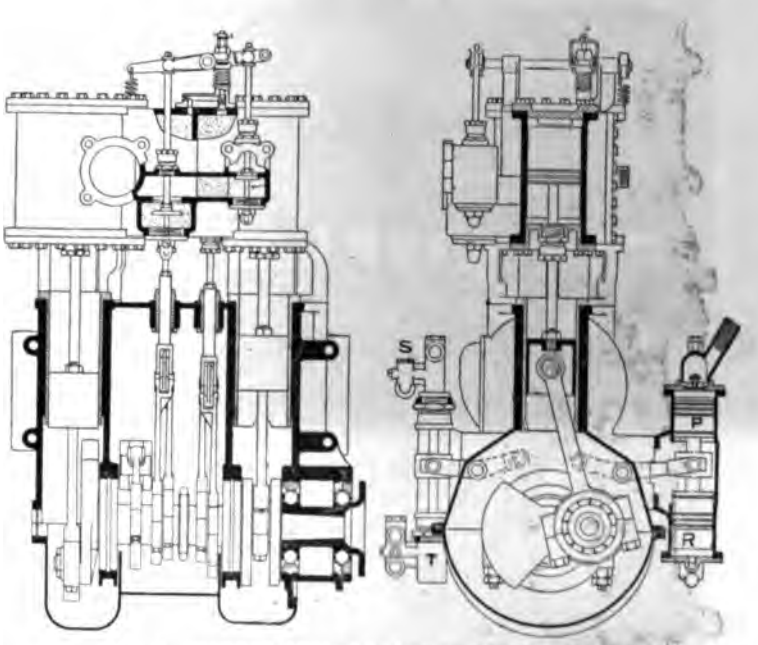


FIG. 6 SECTION AND ELEVATION OF THE ENGINE

that the operation of the White system is very different from that of the ordinary steam plant, and that the operator has little more to do than to control the motions of the engine, the steam generator providing steam when required. As used in the steam car the pressure is not likely to fluctuate materially, for the reason that the water and fuel supply vary in accordance with the demand. The generator will supply a large amount of steam when a large amount of power is required and a small amount when but little power is needed.

purposes of starting or for obtaining a large amount of power for use in an emergency. The valves are driven from double eccentrics through the medium of Stephenson links, and are operated in essentially the same manner as those in use in the ordinary steam locomotive,

FIG. 8 BACK VIEW OF CONDENSER

i. e., the point of cut-off can be changed and the engine reversed by a movement of the link. A view partly in section of the engine is shown in Fig. 6, which will be readily understood without further explanation. The engine is directly connected to various pumps

already referred to which consist (1) of an air pump that is used to maintain an air pressure on the fuel tank for the purpose of regulating the feed of oil to the boiler, shown at *P*, (2) a vacuum air pump shown at *R*, also two boiler feed pumps shown at *I* and *S*. The one shown at *T* is provided with a by-pass controlled by the steam pressure as described, the other shown at *S*, with a by-pass controlled by hand. These pumps are simple plunger pumps with practically no mechanism to get out of order. A front perspective view of the engine is shown in Fig. 7.

THE CONDENSER

18 The steam system is provided with an air condenser which in its application to a motor car is placed at the front of the vehicle. It consists of a series of corrugated copper pipes with suitable header

FIG. 9 THE CHASSIS

connections at top and bottom, and is arranged to receive the exhaust steam into the upper header.[1] The condensed water falls by gravity to the lower header and is removed by a pump. The tubes are surrounded by air, which is circulated by the motion of the vehicle supplemented by the use of a fan located between the engine and the condensing surface. The condenser is furnished with a relief valve which opens to exhaust steam into the air in case the back pressure becomes of sensible amount. The condenser as applied to motor cars previous to 1907 was not adapted to produce a sensible vacuum, its purpose being to conserve the water supply.

[1] The condenser dimensions are as follows: For E and F cars (1905–6) 74 tubes, 24.5 inches long, with a total surface of 118 sq. ft. For car (1907) of 65 tubes, 27 inches long with a total surface of 136 sq. ft.

19 Recent improvements in the pumping system give a substantial vacuum from which a considerable increase in economy, due to the vacuum, is anticipated in the future. The motor car of 1907, it is expected, will maintain a vacuum of over ten inches at a speed of 20 miles per hour.

ARRANGEMENT OF PARTS

20 The arrangement of the power plant as applied to a motor car, is not especially pertinent to this article, but being of considerable general interest, is shown in the accompanying view of the chassis, Fig. 9, in relation to the supporting framework and the propelling wheels. The boiler occupies a position somewhat back of the center of the frame and discharges the products of combustion downward and to the rear; the condenser occupies a position at the extreme front, the

FIG. 10 THE CAR COMPLETE WITH TOURING STYLE OF BODY

engine a position just back of the condenser, and the water tank a position just in the rear of the engine. When the body of the vehicle is in position the forward seat is located directly over the boiler and an ornamental hood is placed over the engine and the space between the water tank and condenser. The throttle valve of the engine is controlled by the small hand wheel located above the steering wheel.

21 The engine is connected to the rear axle by a shaft drive which is provided with a clutch and one change gear, making it possible to operate the engine independently of the vehicle and also to vary the ratio of speed of crank shaft and rear axle. The car is provided with a double set of brakes, a steering gear controlling levers for the engine,

and a complete equipment of force feed lubricators, which need no consideration in this article.

22 In the usual operation of the car, which is shown complete in Fig. 10, the operator does little more than to steer and open or close the throttle as more or less speed is required. The automatic devices take care of the steam supply except for extraordinary conditions where an unusual amount of power is required; for such cases hand control of the water supply must be employed.

23 The engine is operated with steam superheated about 300° under usual conditions of operation, and under such conditions the steam system has shown a high economy.

TESTS OF THE WHITE STEAM PLANT

24 Prof. C. H. Benjamin, of the Case School of Applied Science, Cleveland, Ohio, made a very careful brake test of the steam plant of the White system of 1903 which [illegible]d a 10 h. p. engine and found that when the engine was fully loaded it [illegible]sed only 12.6 pounds of steam per brake h. p. hour and 1.16 pounds [illegible] gasolene per h. p. hour. These results are unprecedented for small steam plants of any size and are nearly equal to the best results obtained with large triple expansion condensing engines. Some details and results of this test are given as an Appendix.

25 I conducted a test of the boiler and engine for the 1907 car from July 9 to 17, 1906, being assisted by Mr. Walter Grothe, M.E., engineer for the White Sewing Machine Company, Prof. W. N. Barnard, M.E., of Cornell University, Mr. Wm. Scaife, and Mr. George Carpenter, M.E.

26 The engine and boiler tested have essentially the same features of design as those previously used, but are somewhat larger and have increased power. The engine used in the White steam cars of 1905 and 1906 had cylinders 3 and 5 inches in diameter by 3½ inches stroke, and was rated at 18 h. p. The one tested had cylinders 3 and 6 inches diameter by 4½ inches stroke, and is rated by the company at 30 h. p.

27 *Dimensions of Engine for 1907 car.*

Diameter of cylinders, 3″ high pressure, 6″ low pressure.
Diameter of piston rods $\frac{9}{16}$″ high, $\frac{9}{16}$″ low.
Clearance of engine, 17.9% high, 19.3 % low.
Weight of cylinder castings with guides, 98.5 lbs.
Weight of engine frame complete, 201.5 lbs.
Weight of valves and fittings, 28.0 lbs.
Total weight, engine complete, 328 lbs.

BOILER

28 The boiler consists of nine coils of drawn tubing with a nominal internal diameter of ½ inch, actual internal diameter of 0.53 inch, actual external diameter 0.72 inch. The external diameter of the boiler is 22 inches; its height, 11 inches. The boiler contains 243 feet in length of ½ inch tubing, and has a heating surface which is calculated as amounting to about 45.8 sq. ft.

29 The weight of the boiler without fittings is 150 lbs. The weight of casing, bolts, and all the fittings is 125 lbs. additional, making the total weight of the boiler complete as 275 lbs. The weight of burner is 40 lbs. From this it is noted that the total weight of the power system is about 643 lbs. The maximum brake horse power, as shown on the test, is about 45, hence the weight is about 14.3 lbs. per D. H. P.

30 On account of the diminutive size of the engine, its lack of governor, and the high speeds at which it is adapted to run, it was decided to make the economy test of the steam plant on the basis of delivered or brake horse power rather than that of indicated horse power. It was also believed that the use of the indicator would detract sensibly from the power and economy of the engine because of its small steam cylinders, and it was further not considered probable that indicator diagrams could be satisfactorily taken at the high speeds desirable in the operation of the engine and in the brake tests. Two series of tests were made, the first without and the second with indicators.

31 For the purpose of testing, the engine was mounted on the frame of a car in the same manner as in the completed motor car, which was, however, supported by solid posts instead of by wheels. The main shaft of the engine was connected to a plain piece of shafting about 6 feet in length and $1\frac{15}{16}$ inches in diameter with one end supported by a plain pedestal bearing resting on fixed foundation. An Alden Prony brake, the construction of which has been previously described before the Society (Transactions, Vol. 11, p. 959), was used to absorb and measure the power. This particular brake had an arm 26.25″ which was of such length as to absorb one horse power at 100 r. p. m. for 24 lbs. supported on the brake arm. During the test the brake arm was supported horizontally by a pedestal standing on a pair of platform scales. The load was applied to the brake by water pressure obtained for the light runs from the water mains of the building and for the heavy runs from the delivery of a special pressure pump. The gross reading of the brake weighing scale which included the unbalanced brake arm and pedestal, as determined by trial, was 12 lbs. greater than the net or corrected scale reading.

32 It was not possible under the existing conditions at the time of the test to provide the necessary current of air for condensing purposes, consequently the tests had to be made with the engine running non-condensing. The weight of steam used by the engine was determined by weighing the feed water supplied to the boiler.

33 The gasolene for the test was carried in a closed tank resting on a pair of scales on which was maintained sufficient air pressure to force it into the furnace. The amount used was obtained by noting the difference in the scale readings and was taken at intervals of ten minutes during the tests. The connections from the tank for the discharge of oil and supply of air were of flexible hose arranged practically horizontal, with considerable slack, and, so far as I could determine by careful check readings, did not affect the difference of the weights of the gasolene tank and its contents.

34 The feed water was supplied from an open tank supported on a pair of scales and connected to the feed pumps in a manner similar to that already described for the gasolene tank. The overflow from the feed pumps was returned directly to this tank so as to render any correction from this cause unnecessary. The three weighing scales were tested and found accurate. The engine was fitted with two feed water pumps, one with the by-pass regulated automatically by the thermostat, the other with the by-pass regulated by an attendant, as already described.

35 Temperatures and pressures of the steam were taken, near the point of leaving the boiler, and also after it had passed the engine throttle and just before entering the steam chest; this distance was short and the connecting pipes and fittings were thoroughly lagged. Temperatures were also taken of the room, the feed water, and the boiler flue.

36 The number of revolutions per minute was determined by a calibrated tachometer and also by a motor car speedometer connected to the main shaft.

37 In making the tests a given load was applied to the brake and the brake beam kept constantly floating by an attendant. The engine speed was maintained practically constant by an operator at the throttle, who kept the needle of the speedometer uniformly at a mark on the dial corresponding to the desired speed. The speed was also determined by frequent readings of the tachometer. The steam pressure and temperature was maintained as nearly constant as possible by use of the automatic devices aided by hand control of the by-pass of the auxiliary pump as required. It frequently took some little time to get the conditions uniform, but after these were obtained,

there was no particular difficulty in maintaining it, and check runs, which were made at several times, were always found in close agreement to the original ones. It will be remembered that the boiler of this car is not provided with a water gage, and as a consequence it does not have a fixed water level. From the closeness with which runs of the same brake load and speed checked at different times, it is probable that for the same working conditions of temperature pressure and load, the water level remained at about the same height or at least did not sensibly vary during the run.

38 The engine was operated at speeds varying from 500 to 1200 r. p. m. in some preliminary tests, from which it was decided to make the principal series of tests at a speed of about 850 r. p. m. It was further decided to make a series of tests at constant speed and brake load, varying in length from ½ to 2 hours, instead of one long test. Several check runs were made which indicated that the errors due to this method of testing were small and not such as to seriously affect the results.

39 In presenting this paper I have given only the average results of the various runs, as it seems unnecessary to publish the figures taken in the various logs, since they differ, in most cases, very little from the average and would greatly increase the length of the paper. The results of the tests with the Alden dynamometer are given in Tables 1 to 4 and in diagrams which follow.

INDICATED HORSE POWER TESTS

40 After the brake tests, at a speed of 850 r. p. m., had been completed, steam engine indicators were applied, and a test was made for the purpose of ascertaining, if possible, the relation of brake horse power to indicated horse power. With the facilities at hand it was found impossible to get reliable diagrams at a speed greater than 475 r. p. m. For that reason it was decided to determine the relation of brake horse power to indicated horse power at a lower speed than the brake test. The results are given in Table 5.

TABLE 1

41 A little explanation is, I believe, required in order to understand thoroughly the results as given in the accompanying tables and diagrams. Table 1 gives the average results in the various brake tests of pressures, temperatures and degrees of superheat. It will be noted by reference to this table that during the various tests from 6 to 17, the boiler pressure averaged 595 lbs., the steam

chest pressure varied with the load from 152 lbs. to 427 lbs., averaging 303 lbs. The temperature of the steam near the boiler averaged 783° F., that in the steam chest, 757° F. This indicates that the steam leaving the boiler was superheated nearly 300°, that entering the steam chest about 340°, and that exhausted about 28°, so that the steam in its entire passage through the engine remained in a superheated condition.

42 The temperature for the boiler steam, as given in the table, is that corresponding to the usual running conditions; this, as already explained, is controlled by a thermostat which is set to maintain a

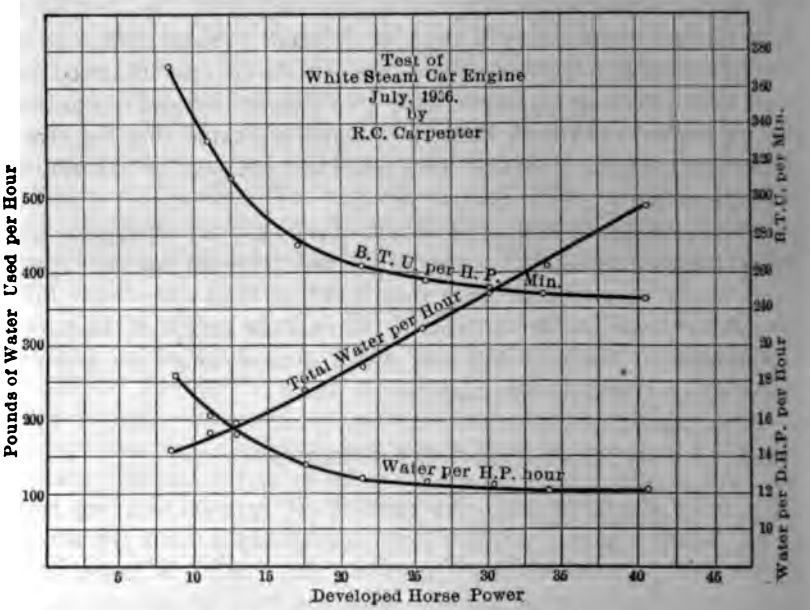


FIG. 11 ECONOMIC RESULTS OF TEST

temperature of about 420° C. or 790° F. It is believed by the writer that better results are obtained in the practical operation of the car with steam at that temperature than with steam at a lower temperature. This also corresponds to certain tests which I conducted and which are in the lower part of the table, although numbered 1, 2, 3 and 4. The results of these tests differ principally from those numbered 6 to 17, in the temperature of the steam. In runs 1 to 4 the exhaust steam contained but little superheat. The amount of steam per D. H. P. per hour for these conditions averaged 13.3 lbs., whereas for the same load with the higher degree of superheat, as shown in run

6, the average was 12.7 lbs. per D. H. P. per hour. The writer is not prepared to give any explanation of this condition, which was unexpected, but it is probably due to the entire absence of condensation at the higher degree of superheat.

43 This condition is shown by reference to the combined diagram, Fig. 15, corresponding to the cards No. 6, Fig. 13, which were taken with a 60 lbs. net brake load, corresponding to 21.25 h. p. at a speed of 850 r. p. m. An expansion curve for the same weight of saturated steam is shown by the dotted line A—B which is marked "saturation curve." It is noted that the steam was slightly superheated from cut-off to release in the high, and greatly superheated in the low.

TABLE 2

44 The results given in the first seven columns of Table 2, including that for the water per D. H. P. per hour, are calculated from the data obtained in the test. The remaining portion of the table gives the heat in British thermal units above 212° F., which is received by the engine and is calculated (for the saturated part) from the heat given in the Buel steam tables[1] corresponding to the pressure in the steam chest; to this is added the heat obtained for the superheated part, which is found by multiplying the degree of superheat, in the steam chest by the corresponding specific heat of steam, as shown on the accompanying diagrams, Figs. 11 and 12. The total B. t. u. per pound is the sum of that contained in the saturated part and in the superheated part. From this latter amount there was calculated the B. t. u. supplied the engine above 202° per D. H. P. per minute.

45 The principal economic results of this table are shown on the diagram, Fig. 10, in relation to the total delivered horse power, from which it is noted that, with the exception of the light loads, the diagram representing the total weight of steam in relation to the total delivered horse power is a straight line. At light loads the line curves slightly upward and away from the straight line. The economic results at very light loads could not be obtained because of the friction of the brake even when the water pressure was off.

EFFECT OF HEATING—FEED WATER

46 In Table 2 the heat supplied to the engine was calculated from 212°, although the actual feed water was 78° F. The actual evaporation from feed water at 78° F. to steam with pressure and

[1] The Buel steam tables are of established accuracy and were the only ones at my command which were extended to high pressures.

temperature as shown averaged 10.34 lbs., of water for one pound of gasolene. During the tests no exhaust feed water heater was used but a heater consisting of a coil of copper pipe containing slightly less than 2 square feet of heating surface was, immediately after the close of the tests recorded in Tables 1 and 2, inserted in the exhaust in such manner that the feed water entering the boiler would be forced through it. A test was made to determine the effect of this heater by Mr. Scaife, who was one of my assistants during the tests which I made. This test showed that the temperature of feed water was raised by the heater from about 75 to 205° F., and that in so doing the actual evaporation per pound of gasolene was increased from 10.34 to 11.5 lbs. The results of these tests are shown in Table 3. As the cars for 1907 will be equipped with a heater containing about 3 sq. ft. of heating surface, it is believed to be fair assumption to consider that the feed water will enter the boiler at a temperature of

TABLE 1

AVERAGE RESULTS OF VARIOUS RUNS IN BRAKE TESTS

NO. OF RUN	PRESSURES		TEMPERATURES, DEGREES F						DEG. OF SUPERHEAT			SPECIFIC HEAT[1]
	BOILER	STEAM CHEST	BOILER	STEAM CHEST	EXHAUST	FEED WATER	BOILER FLUE	ROOM	BOILER	STEAM CHEST	EXHAUST	
6 (2 h.)	480	275	790	763	244	87	562	81	324	349	32	.59
6 (1 h.)	480	275	790	763	244	87	562	81	324	349	32	.59
6 (1.5h.)	480	275	790	763	244	87	562	81	324	349	32	.59
7	511	152	777	730	248	74	463	83	305	364	36	.54
8	594	179	783	748	246	74	463	82	295	370	3	.54
9	525	240	779	752	246	75	465	83	307	352	34	.58
10	496	275	778	762	240	76	488	84	309	348	28	.59
11	506	180	780	743	247	76	460	84	318	365	35	.54
12	650	312	782	754	228	78	585	85	283	330	14	.59
13	625	305	778	750	244	75	580	90	284	328	32	.60
14	623	390	788	765	236	79	573	83	284	320	24	.62
15	675	427	783	767	234	75	590	83	281	317	22	.62
15a	675	427	783	767	233	75	590	83	281	317	21	.62
15b	675	350	783	767	236	75	600	83	281	331	24	.61
16	725	370	792	768	237	81	600	83	280	328	25	.61
17	608	426	783	766	232	83	540	83	293	316	20	.62
Average	595	303	783	757	239	78	543	83	298	339	28	.582
1	495	200	734	706	225	76	500	80	265	319	13	
2	540	265	734	706	212	75	490	81	256	299	0	
3	556	275	725	689	212	75	490	83	244	275	0	
4	570	250	725	698	220	81	535	84	246	293	8	

[1] Computed from diagram, Fig. 12, as explained.

TABLE 2

ECONOMIC RESULTS OF BRAKE TESTS

NO. OF RUN	R. P. M.	NET BRAKE LOAD, LBS.	BRAKE H.P.	TOTAL LBS. WATER PER HOUR	TOTAL LBS. GASOLENE PER HOUR	WATER PER D.H.P. PER HOUR	B. T. U. ABOVE 212° TO ENGINE PER LB. OF STEAM: SATURATED PART	SUPERHEATED PART*	TOTAL	B.T.U. PER D.H.P. PER MINUTE	ACTUAL EVAPORATION PER POUND GASOLENE	ACTUAL EVAPORATION PER SQUEEZE FOOT PER HOUR
6 (2 h.)	850	60	21.25	269.75	26.25	12.69	1027	205	1232	261	10.25	5.86
6 (1 h.)	850	60	21.25	266.5	26.25	12.54	1027	200	1232	261	10.15	5.77
6 (1.5h.)	850	60	21.25	269.0	26.33	12.66	1027	205	1232	261	10.20	5.85
7	850	60	8.5	156.0	14.81	18.35	1014	197	1211	370	10.51	3.40
8	850	31.25	11.07	180 0	18.00	16.30	1018	200	1218	371	10.00	3.92
9	875	48	17.50	234.5	22.5	13.40	1024	204	1228	275	10.40	5.10
10	850	60	21.25	269.0	25.25	12.66	1029	206	1235	262	10.65	5.86
11	850	36	12.75	195.0	18.5	15.32	1018	197	1215	309	10.55	4.25
12	850	72	25.50	320.0	31.0	12.55	1031	195	1226	256	10.31	6.90
13	850	72	25.50	322.0	31.25	12.57	1030	196	1226	258	10.30	7.02
14	850	72	25.50	320.0	31.125	12.55	1034	198	1232	257	10.30	6.98
15	850	85	30.1	370.0	31.125	12.29	1036	196	1234	252	10.42	8.07
15a	850	85	30.1	370.0	35.5	12.29	1038	196	1234	252	10.42	8.07
15b	850	85	30.1	371.5	35.5	12.30	1035	202	1237	253	10.45	8.11
16	850	96	34.0	408.8	39.25	12.05	1036	200	1236	246	10.40	8.87
17	850	115	40.7	488.0	48.0	11.96	1037	197 av.=	1224 1228	244 av.	10.15 10.34	10.7
1	700	68	19.8	265	26	13.4						
2	850	60	21.25	280	27¾	13.2	Runs 1 to 4 made with less superheat than runs 6 to 17					
3	860	60	21.25	284	27	13.3						
4	950	60	23.9	320.0	30.8	13.3						

*Calculated as explained in text.

NOTE—The equivalent evaporation from and at 212° F. is not computed in this text. It is approximately equal to the actual evaporation multiplied by 1.42.

TABLE 3

TEST BY MR. SCAIFE, WITH FEED WATER HEATER

R. P. M.	NET BRAKE LOAD LBS.	BRAKE H. P.	TOTAL LBS. WATER PER HR.	TOTAL LBS. GASOLENE PER HR.	WATER PER D. H. P. PER HR.	ACTUAL EVAP. PER LB. GASOLENE	TEMPERATURES, DEGREES F. FEED WATER A	FEED WATER B	EXHAUST	BOILER
875	72	26.25	331	29	12.6	11.4	75	203.2	239	752
850	48	17.00	232	20	13.6	11.6	75	204.8	259	751
850	22	7.4	138	12	18.6	11.5	75	205.0	280	750

A. Temperature entering heater; B, leaving.

about 212°, in which case the actual heat would be substantially that shown in Table 2.

47 The above results compared with the results recorded in Table 2 show an increase in actual evaporation of 1.2 lbs. of water per pound of gasolene, due to the use of a feed water heater in the exhaust. This indicates an increase of economy of 10.4%. The heat added by the feed water heater averages 130 B. t. u. per pound. As there are about 1230 B. t. u. in each pound of steam supplied the engine, this indicates that 10.6% of the total heat, as compared with the previous tests, is supplied by the eater and is a fair check on the accuracy of the tests shown in Ta e 2.

SPECIFIC HEAT OF SUPERHEATED STEAM

48 It will be noted that in calculating the results given in Table 2, relating to the heat received by the engine, the specific heat of steam was assumed to vary, and further, that it was taken as considerably greater than the value gi en by Regnault.

49 I will refer here briefly to the source from which these values were obtained. The laboratories at Sibley College, which are under my direction, have been working at the problem of the measurement of the specific heat of steam at intervals during the last ten years. Various methods have been tried out and abandoned and others instituted in their place. The methods employed have generally been those which would measure the heat given off in passing from a higher to a lower degree of superheat, or *vice versa*, independently from the total heat in the steam, as in that way, it was hoped to avoid the errors which are always caused by measuring the total heat which is great in comparison with that used in superheating. The various methods tried were, first, measuring the heat required for superheating by a known drop in pressure, being in many respects the reverse of the method used with the throttling calorimeter for measuring the quality of steam. A second method tried was to measure the heat given off by the steam at constant pressure when being cooled from a high degree to a lower degree of superheat. The third method was the reverse of this and consisted in measuring the heat required to raise the temperature from a lower to a higher degree of superheat by the electric current, This latter method has proved the most satisfactory; although great difficulty has been experienced in getting accurate and satisfactory apparatus for producing the necessary electric current uniformly and in obtaining suitable instruments for measuring the increase in temperature.

50 For the final results we are indebted very largely to Prof. Carl C. Thomas, Mr. C. E. Burgoon, and to the coöperation of the testing department of the General Electric Company in charge of Dr. W. R. Whitney. We are also indebted to Mr. M. E. Berry for the preliminary work in testing out the methods. Prof. Carl C. Thomas became interested in the determination of this result in connection with his investigation of the steam turbine and was engaged by the General Electric Company to conduct experiments for this purpose in the summer vacation of 1905. While these experiments led to no immediate results, they enabled Professor Thomas to design apparatus built by the General Electric Company which gave satisfactory

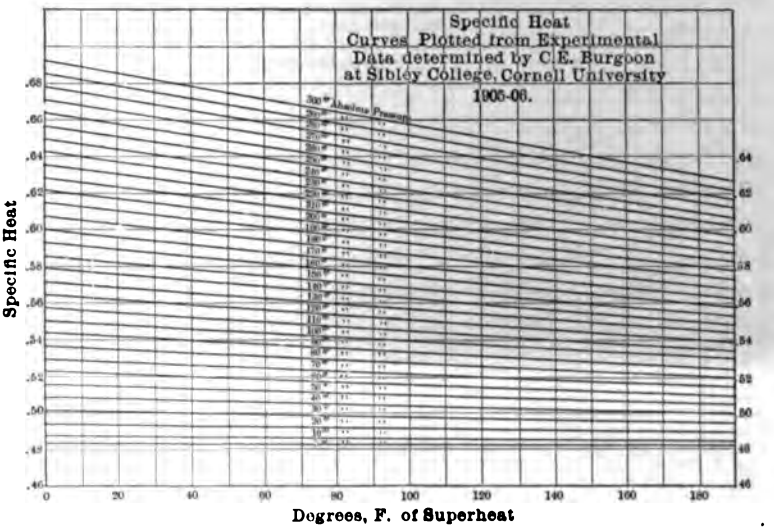


FIG. 12 SPECIFIC HEAT OF SUPERHEATED STEAM

and reliable results, when operated later at Sibley College by Mr. Burgoon. The temperature measurements were made first with high grade mercurial thermometers, which, however, gave irregular results. Platinum resistance thermometers were then tried which on test proved very satisfactory but which later gave results which could not be checked. Nickel-steel constant in thermal junction thermometers, which were made by Professor Shearer of the Physics Department of Cornell University, and calibrated by use of their standards, were then substituted. These proved to be reliable and gave accurate results which could be checked by experiments made later. The experiments covered a range of pressures from 0 to 220 lbs. by gage and a range of superheat for these pressures to about 400° F.

The results show an increase of the specific heat of superheated steam with increase in pressure and also a decrease in the specific heat of superheated steam with increase in the degree of superheat for constant pressure. The experiments show that for a given degree of superheat the specific heat increases directly with increase of pressure. The results are shown on the accompanying diagram, Fig. 12.

51 The experiments for determination of specific heat will be continued by Professor Thomas during the coming year through greater ranges of pressure and superheat, and the results will be presented in a paper before the society which Professor Thomas will prepare for a later meeting. The results which he has found are somewhat lower

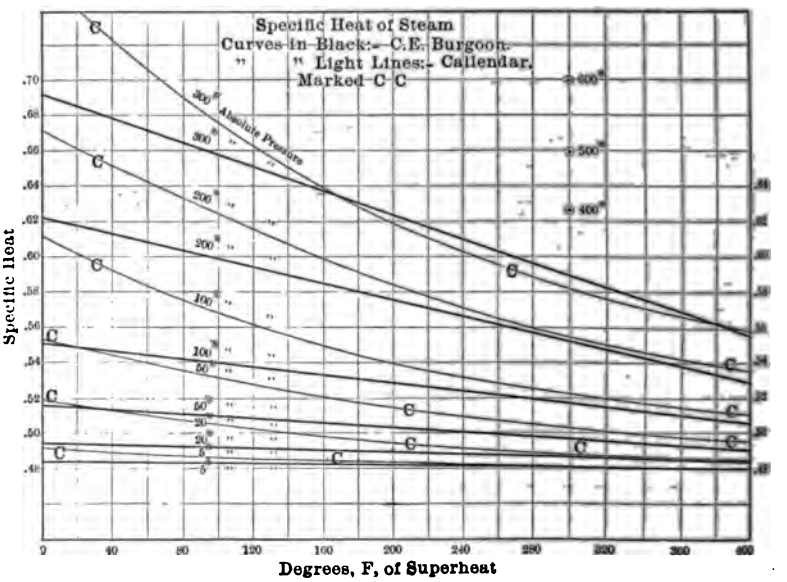


FIG. 13 COMPARISON OF SIBLEY COLLEGE RESULTS WITH THOSE OF PROFESSOR CALLENDER

than those given by Professor Callender for low degrees of superheat, but essentially the same for high superheat. The Sibley results produced beyond the range of the experiment to high pressures and temperatures are shown in Fig. 13, compared with those by Callender.

52 It has not been proved experimentally that the specific heat continues to increase indefinitely with increase in pressure, as shown in Fig. 13. It is also true that in the tests which I made the pressures were much higher than those used in the experiment for specific heat as seen by consulting Fig. 12, but from the fact that there is no other data available for computing the heat at high pressures

and high degrees of superheat, I decided to use the results of diagram Fig. 13, in computing the amount of heat supplied to the engine. The result of this method of computation is to charge the engine, on the average, with about 35 B. t. u. per lb. of steam more than by considering the specific heat of steam as constant, and equal to 0.48.

THE INDICATOR TESTS

53 The results of the indicator tests are shown in Table 4. These results indicate that the work lost in friction at about 460 r. p. m. averages 1.45 h. p. This includes the friction of the engine which has ball bearings throughout, the friction of one plain bearing used to support the brake shaft, and the work of operating the boiler feed pumps but not the air pumps. In the computations for the economic results per indicated horse power for tests at 850 r. p. m. I have assumed the friction of the engine to be 1.6 horse power which I believe to be nearly correct. The experiments made do not show an increase in friction with change of load and the highest and lowest results differ about ½ horse power from the mean, which no doubt can be accounted for by the difficulties of obtaining accurate diagrams under the conditions of the test.

54 The diagrams of the high pressure cylinder were taken with a 200 pound spring and those for the low pressure with a 60 pound spring. A set of indicator diagrams, reproduced by photographing the originals, taken with the link in different positions is shown in Fig. 14 and 15 from which it is noted that the cut-off varies with different positions of the link in the high pressure cylinder from 10 to 75 per cent. A combined diagram of indicator cards No. 6 is shown in Fig. 16 on which a curve showing the volume of the same weight of saturated steam is indicated by a dotted line. This line shows that the steam was slightly superheated from cut-off to release in the high pressure cylinder and considerably superheated throughout the low pressure cylinder, and that there was no shrinkage of volume in either cylinder due to condensation.

TABLE 4
RESULTS OF INDICATOR TESTS

NO.	M.E.P.		I.H.P.		TOTAL		NET BR'K LOAD	BRAKE H.P.	FRICTION H.P.	R.P.M.	STEAM CHEST PRESS.	CONDITION OF LINES FROM CENTER	CUT-OFF RIGHT %
	H	C	H.	C.									
1 H	90.0	100.5	3.30	3.65	6.95		—			—	—		—
1 L	26.6	18.3	24.0	2.68	5.08	12.03	57	10.90	1.13	365	195	2d notch	37
4 H	75.0	80.5	2.74	2.81	5.55		—			—	—		—
4 L	28.2	24.5	4.16	3.58	7.67	13.32	60	11.50	1.72	460	205	1st notch	42
6 H	94.5	92.5	3.46	3.25	6.71		—			—	—		—
6 L	16.5	20.6	2.44	3.02	5.46	12.17	57	10.91	1.26	460	195	1st notch	43
7 H	92.5	100.7	3.38	3.51	6.89		—			—	—		—
7 L	18.2	25.0	2.98	3.65	6.63	13.42	60	11.50	1.92	460	205	2d notch	37
8 H	77.5	92.5	2.84	3.25	6.09		—			—	—		—
8 L	20.4	28.2	3.02	4.12	7.14	13.23	60	11.50	1.73	465	300	3d notch	14
9 H	84.5	83.0	3.1	2.9	6.0		—			—	—		—
9 L	28.1	29.7	4.0	4.3	8.3	14.3	65	12.42	1.88	465	410	4th notch	9-11
10 H	21.8	191.3	7.95	6.7	14.65		—			—	—		—
10 L	40.3	36.7	5.95	5.35	11.3	25.95	128	24.5	1.45	460	300	full stroke	72-82
13 H	74.2	65.7	2.71	2.30	5.01		—			—	—		—
13 L	–	–	.28	.28	.56	5.57	24	4.6	.97	460	80	full stroke	78
14 H	41.7	42.8	1.53	1.50	3.03		—			—	—		—
14 L	9.5	9.12	1.41	1.33	2.74	5.77	24	4.6	1.17	460	180	2d notch	28
16 H	66.0	70.2	2.42	2.45	4.87		—			—	—		—
16 L	17.1	19.5	2.52	2.84	5.36	10.23	48	9.2	1.03	460	250	2d notch	22
17 H	126.0	120.0	4.61	4.20	8.81		—			—	—		—
17 L	21.4	22.2	3.17	3.10	6.27	15.08	72	13.80	1.28	460	185	full stroke	75
18 H	97.5	98.5	3.53	3.45	6.98		—			—	—		—
18 L	26.5	30.7	3.94	4.48	8.42	15.40	72	13.80	1.60	460	300	2d notch	21
19 H	131.0	139.0	4.80	4.86	9.66		—			—	—		—
19 L	24.2	21.7	2.58	3.17	5.75	15.41	72	13.80	1.61	460	200	full stroke	73
20 H	76.5	97.0	2.80	3.40	6.20		—			—	—		—
20 L	29.6	30.7	4.38	4.48	8.86	15.06	72	13.80	1.26	460	350	2d notch	22
21 H	149.0	145.0	5.45	5.08	10.53		—			—	—		—
21 L	30.5	35.7	4.52	5.21	9.73	20.26	96	18.35	1.90	460	300	1st notch	38-42
22 H	139.0	162.0	5.08	5.67	10.75		—			—	—		—
22 L	31.1	32.2	4.60	4.70	9.30	20.05	96	18.35	1.70	460	310	1st notch	45
23 H	92.5	112.0	3.38	3.92	7.30		—			—	—		—
23 L	21.7	26.0	3.21	3.80	7.01	14.31	70	13.40	0.91	460	230	1st notch	45
24 H	77.8	79.15	2.85	2.78	5.63		—			—	—		—
24 L	21.7	20.2	3.21	2.95	6.16	11.79	52	9.95	1.84	460	165	1st notch	43
25 H	52.2	49.2	1.91	1.71	3.62		—			—	—		—
25 L	7.7	8.0	1.14	1.72	2.31	5.93	24	4.6	1.33	460	100	1st notch	43
27 H	156.5	151.0	5.73	5.28	11.01		—			—	—		—
27 L	35.2	38.0	5.24	5.65	10.89	21.90	180	20.6	1.30	460	400	1st notch	43
28 H	143.0	174.0	5.37	6.10	11.47		—			—	—		—
28 L	38.0	43.2	5.62	6.30	11.92	23.39	114	21.9 Ave.	1.46 1.45	460	475	1st notch	45

H = High pressure cylinder
L = Low pressure cylinder

THE FUEL

55 The fuel used in the test was gasolene supplied by the Standard Oil Company. Its specific gravity, as measured by a Beaume hydrometer, reduced to a temperature of 60° F. was 68.5, which corresponds to a specific gravity of 0.705 at 60° F. Its specific gravity, as meas-

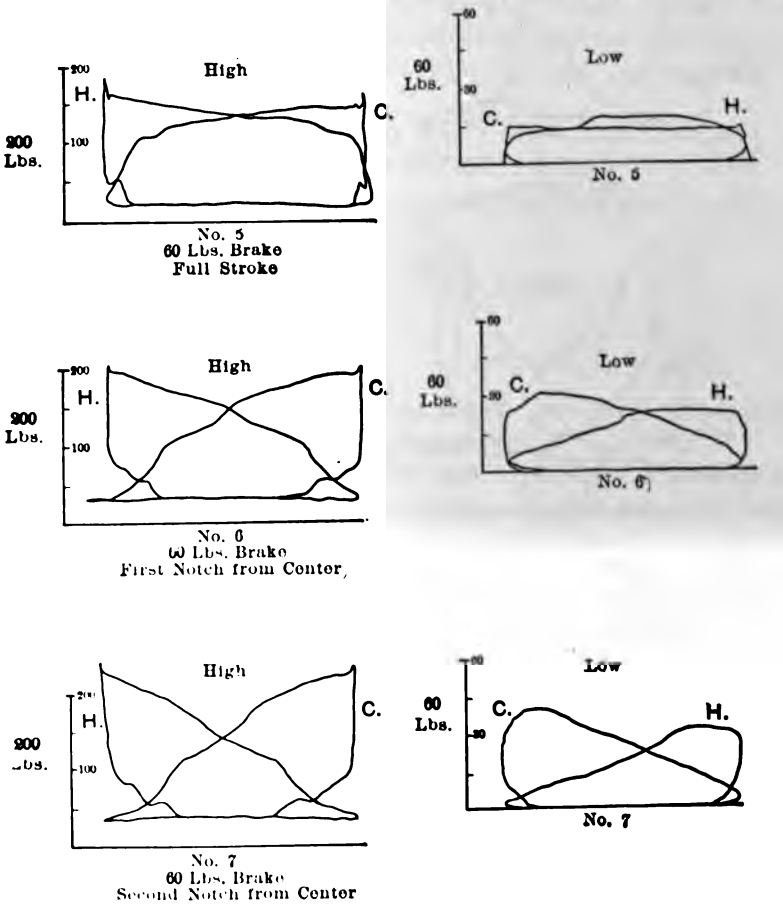


FIG. 14 SAMPLE INDICATOR DIAGRAMS

ured at a temperature of 75°, was 0.6945, water being 1. From this measurement a gallon of gasolene at a temperature of 60° should weigh 5.877 lbs.

56 The heating value of this oil as determined by Prof. H. Diedeichs, as the average of three determinations, with the Junker calorimeter, is 19,606 B. t. u. per pound for the higher value uncorrected

for water vapor and 18,482 B. t. u. per pound for the lower value corrected for water vapor. The chemical analysis of the oil, as made by Prof. B. S. Cushman of Cornell University, showed 84.76 per cent

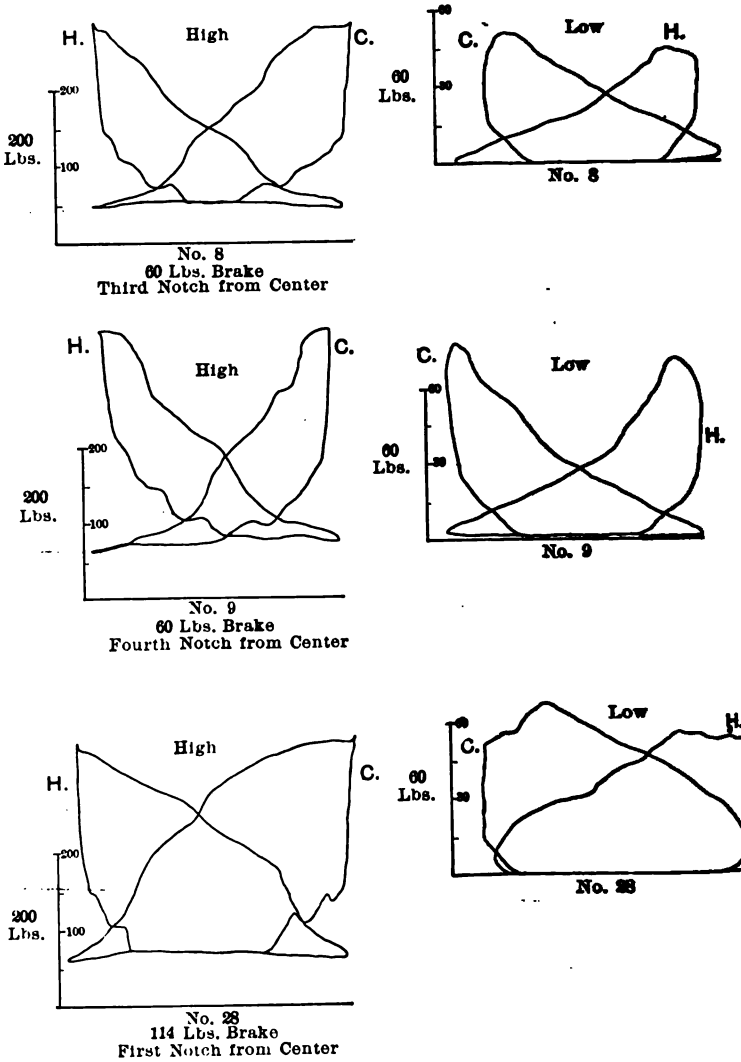


FIG. 15 SAMPLE INDICATOR DIAGRAMS

C, 15.24 per cent H, from which the heating value per pound, by calculation, is 20,400 B. t. u. The lower calorimetric value is about 10% below the theoretical calculated value, a discrepancy which I am not prepared to explain at the present time, but which I judge

from consultation of a few authorities has occurred a number of times before. I consider the lower calorimetric value as more nearly representing the value of the fuel in practice than the other.

THE BOILER TEST

57 The average pressure of steam at the boiler during the various runs was 595 pounds. The average degree of superheat at the boiler was 298 degrees. The mean temperature of feed water was 78 degrees. The average evaporation was 10.34 lbs. of water for one pound of gasolene.

From this data, by consulting Buel's steam tables, we find

B. t. u. per pound of steam above	212°	= 1051
B. t. u. per pound for raising feed to	212°	= 144

By producing lines in Fig. 13, the

Specific heat is found to be 0.69

Heat required to superheat 298° = 298 × 69 = 206

Total.....1401

Equivalent evaporation from and at 212° per sq. ft. of heating surface per hour, was 13 lbs. for highest result.

58 In the above calculation the heat required for superheating is extremely approximate as the pressures in my test were about three times as high as those in the Sibley College test for specific heat of steam. In this last calculation I have obtained the specific heat as 0.69 by extending the lines in Fig. 13. This quantity gives the value of the heat in one pound of steam above 212° as 1257 B. t. u., which averages about 29 B. t. u. per pound higher than that which I calculated as supplied to the engine, and is, I believe, too high since the loss of heat between the points where the two observations were made was small and in my opinion must have been less than 1% or about 14 B. t. u. in this case. If the heat required for superheating were calculated by using 0.48 for the specific heat the above results would have been 1339 B. t. u. per lb. which is 62 B. t. u. or 4.4% less than the above.

59 The heat absorbed by the steam for one pound of gasolene burned would be, in accordance with the above calculation, 14,486 B. t. u., corresponding to an equivalent evaporation from and at 212° F. of 14.9 lbs. per lb. of gasolene, and made on the supposition that the specific heat of steam is constant and equal to 0.48, it would be equal to 13,845 B. t. u. corresponding to an equivalent evaporation from and at 212° of 14.3 lbs. of water per lb. of gasolene.

60 If the heating value of the gasolene be 18,482 B. t. u. per pound, the respective boiler efficiencies for these two cases would be 78.4% and 75.0%. If the heating value be assumed at 20,400 B. t. u. per pound, the respective efficiencies become 71.2 and 67.3%.

THE EFFICIENCY OF THE ENTIRE PLANT

61 The engine developed a horse power on the brake at its highest load during the various tests with a consumption of 11.96 lbs. of feed

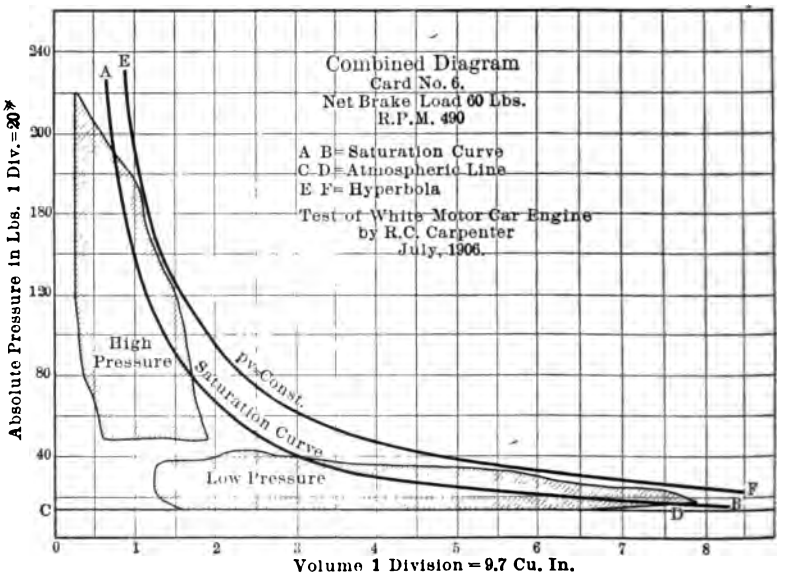


FIG. 16 COMBINED INDICATOR DIAGRAMS

water per hour. The evaporation under actual running conditions with the feed water heater in operation was 11.5 lbs. of water for one of gasolene. This would show that 1.04 lbs. of gasolene would be used under best conditions per developed horse power.

62 If the engine friction be considered as 1.6 horse power, the water per i. h. p. per hour would be as calculated under best conditions, 11.54 lbs. and the gasolene per i. h. p. per hour, 1.004, which is practically one pound of gasolene per i. h. p. per hour.

63 If the gasolene has a heating value of 18,482 B. t. u. per pound, we find a heat efficiency for the whole plant on the basis of total heat supplied, compared with that converted into useful work on the brake, of 13.25% and compared with that indicated of 13.35%. If

the heating value for gasolene be 20,400 B. t. u. per pound the per cent of efficiency for these two cases becomes respectively 12.1 and 12.45%.

64 The above calculations are made to cover the extreme results of the heating values of gasolene, in order to make the results accord with either method of calculation.

SUMMARY OF TESTS MADE BY PROF. C. H. BENJAMIN

65 The test made of the White steam system by Prof. C. H. Benjamin in 1903 has already been referred to, and a summary of the results is given here for comparison with the tests which I made.

66 The engine tested by Professor Benjamin was of the vertical cross compound type with high pressure cylinder 3 inches in diameter, low pressure cylinder 5 inches in diameter, and with a stroke of 3½ inches. Its general construction was in many respects similar to the 1907 engine which has been fully described; it was not, however, provided with ball bearings. The test was made by essentially the same method as described in the paper. During the test the engine was operated at 675 r. p. m., the friction horse power determined in Professor Benjamin's test was approximately 2 which, however, included that of an extra countershaft which was not required in my test.

67 Professor Benjamin's tests show a consumption of water per brake horse power per hour varying from 12.6 to 19.9 and per indicated horse power per hour an amount varying from 10.8 to 14 lbs.

68 Respecting these results, Professor Benjamin states: "This is a remarkable showing for an engine of this size. When the fact is considered that ordinary simple engines use from 25 to 35 lbs. per indicated horse power per hour, and that 12 pounds is considered good performance for triple expansion condensing engines the remarkable nature of this performance is better understood."

69 The following gives the principal results in tabular form of the test made by Professor Benjamin.

PRINCIPAL RESULTS—TEST OF WHITE ENGINE OF 1903

By Prof. C. H. Benjamin

BOILER PRESSURE	TEMP. F.° FEED	TEMP. STEAM (BOILER)	TEMP. STEAM (ENGINE)	SUPERHEAT (BOILER)	SUPERHEAT (ENGINE)	TEMP. (EXHAUST)	WEIGHT GASOLENE PER 30 M.	WEIGHT WATER PER 30 M.	ACTUAL EVAP. PER SQ. FT. H. S PER HOUR	ACTUAL WATER PER H. P. HOUR	GASOLENE PER H. P. HOUR	EQUIV. STEAM PER H. P. HOUR AT 212°	BRAKE H. P.	CUT-OFF
263	51	763	695	353	285	288	6.6	72	3.92	12.6	1.16	16.3	11.4	.75
250	47	779	725	373	319	289	6.5	68	3.71	14.9	1.42	19.7	9.15	.75
274	47	786	739	369	325	360	6.0	68.2	3.72	19.7	1.74	26.3	6.92	open
244	47	772	718	368	314	339	5.7	60.5	3.30	17.5	1.65	23.1	6.92	.75
356	48	782	735	345	298	298	5.3	54.5	2.96	15.8	1.53	20.4	6.92	.50
388	46	793	726	347	280	293	4.6	46.5	2.53	19.9	1.97	25.9	4.66	.50
483	47	796	711	329	244	344	3.0	29.7	1.63	24.8	2.5	31.8	2.4	.50
380	47	737	632	294	189	354	2.0	15.7	0.76	—	—	—	0	.50

APPENDIX

TEST OF BURSTING STRENGTH OF TUBING USED IN THE MANUFACTURE OF THE WHITE STEAM GENERATOR

70 Two sizes of tubes were tested, one size being nominally ½ inch internal diameter but with an actual internal diameter of 0.53 inches and external diameter of 0.72 inches. The other tubes tested had a nominal internal diameter of ⅜ inches, an actual internal diameter of 0.372 inches and an external diameter of 0.53 inches. The tubes are named in the following table by their nominal internal diameter.

71 Before making the test the tubes were threaded and connected by means of short copper tube to a cylinder fitted with a plunger 0.804 inches in diameter (area = 0.508 inches). The tubes and connections were filled with oil and the plunger forced into the cylinder by a testing machine, the pressure being noted.

72 The ends of the pipes were closed with fittings in each case; on half of the tests a steel elbow and plug were used, and for the remaining tests a brass union and brass plug were used. In all cases failure occurred in these fittings and not in the tubes. The internal pressure acted to expand the fittings so as to cause a leak in the joint. The following table shows results of the test.

½ inch tubing, 2 ft. long closed with elbow and plug.

No.	Pressure actual	Pressure per sq. in.	Leakage occurred
1	9600	18900	At joint of elbow and tube
2	8550	16800	At joint of elbow and tube
3	7680	15100	At joint of elbow and tube
4	8600	16900	At joint of elbow and tube

½ inch tubing, 2 ft. long, closed with brass union and plug.

No.	Pressure actual	Pressure per sq. in.	Leakage occurred
1	2950	5800	Between pipe and union
2	3700	7280	Between pipe and union
3	4000	7860	In union
4	3500	6880	In union

⅜ inch tubing, 2 ft. long, closed with elbow and plug.

1	8250	16200	At joint of elbow and pipe
2	6400	12600	At joint of elbow and pipe
3	7670	15100	Around plug
4	9200	18100	At joint of elbow and pipe

⅜ inch tubing, 2 ft. long, closed with brass union and plug.

1	5000	9840	In union
2	4740	9340	Around plug
3	5100	10000	Around plug
4	7040	13850	Around plug

DISCUSSION

PROF. CARL C. THOMAS The curves which Professor Carpenter has presented as giving the values of the specific heat of superheated steam, have been plotted from the results of about seven hundred preliminary experiments made during the past year or more. The apparatus was designed by the writer, upon the basis of about one hundred previously performed experiments, and the work that had already been done under Professor Carpenter's direction, and was most carefully and efficiently operated by Mr. C. E. Burgoon, the holder of a Fellowship in Sibley College, 1905–1906.

2 We do not regard the results of these experiments as necessarily final. It seems probable that they are substantially correct, but their acceptance should be held subject to the results which are expected from the present continuation of the investigation.

3 The general principle of the apparatus is as follows: A given quantity of steam at constant pressure, and a given desired initial

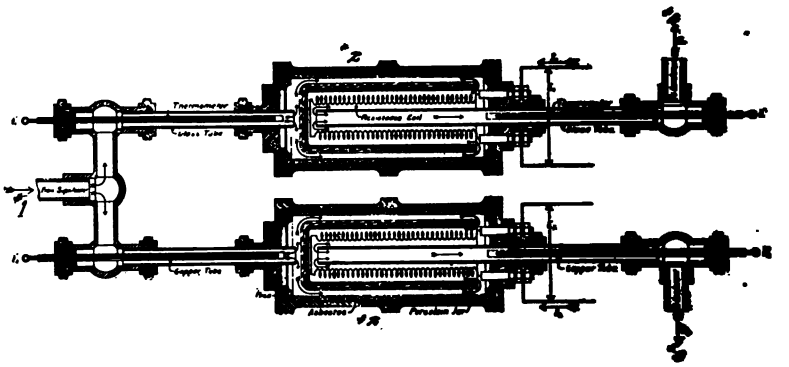


FIG. 1 SUPERHEATING CALORIMETERS FOR DETERMINING THE SPECIFIC HEAT OF SUPERHEATED STEAM

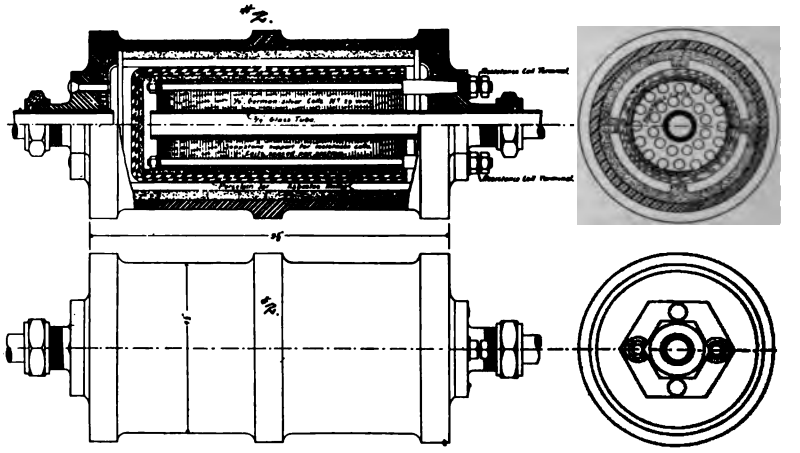


FIG. 2 SUPERHEATING CALORIMETER FOR DETERMINING THE SPECIFIC HEAT OF SUPERHEATED STEAM

superheat, is passed through two exactly similar, electrically heated calorimeters, (marked 2 in all figures) where it is heated by electrical energy. The same quantity of steam is passed through each calorimeter. The two calorimeters are so constructed that there is an equal radiation loss from each, because the containing shell of each calorimeter is jacketed on the inside by steam of the same temperature, that is, by the entering steam, before it is again heated. The steam passes, as indicated by the arrows, Fig. 1, through electrical heating coils so insulated from the entering steam passage that the further superheating does not effect the temperature of the steam next the exterior walls of the calorimeter, and so the radiation remains the same from the two instruments.

4 In one calorimeter enough watts are introduced to heat the steam from the entering temperature of, for example, 250 to 270 degrees. In the other calorimeter, at the same time, the steam is being heated by sufficient watts to raise its temperature from 250 degrees (the same initial temperature) to perhaps 20 degrees higher than the final temperature in the other calorimeter, or 290 degrees.

5 There being the same quantity of steam going through each calorimeter, and the radiation loss from each being the same, the difference in watts required to effect the increases of temperature, stated in the two calorimeters, represents the heat necessary to raise the given quantity of steam through, in this case, 20 degrees, or the difference between 270 and 290 degrees.

6 The steam passes from the two calorimeters through condensers, No 3 and No. 4, Fig. 3 and 4, thence to measuring tubes No. 5 and 6, which have been accurately bored out, and are therefore of uniform diameter. These measuring tubes contain floats operating needle points No. 7. When the discharge valves from the calorimeters are so regulated that these two needle points pass up the scale marked No. 7 absolutely together, then there is the same quantity of steam passing through each calorimeter. When working below atmospheric pressure, closed measuring tubes are used, exhausted by an air pump, and carefully graduated gage glasses supplant the floats and needle points for showing the amount of condensed steam.

7 The steam enters and leaves the two calorimeters through glass tubes which thermally isolate the calorimeters and prevent conduction losses. The temperatures of incoming and outgoing steam are taken by means of thermo-couples placed in the glass tubes.

8 In building up the apparatus one after another of the causes

FIG. 3 SHOWING CONDENSER, ELECTRIC SUPERHEATER, VOLTAGE REGULATOR, ETC.

FIG 4 SHOWING CONDENSERS (3 AND 4), MEASURING TUBES (5 AND 6), ETC.

of error in previous investigations have been attacked and eliminated by providing the following conditions:

a The production of a continuous supply of steam superheated to a given constant temperature and maintained at a given constant pressure. This has been accomplished by passing steam from a small water tube boiler through an electric superheater, No. 1, Fig. 3, before which was placed a separator and throttle valve. The steam pressure is kept uniform by a man at the throttle valve continuously observing a steam gage. The steam passing through the electric superheater at constant pressure is raised in temperature by a constant and thoroughly controlled electrical input, until the steam, upon reaching the two calorimeters, (No. 2 in all figures) is at the given desired initial condition, ready to be heated further in the calorimeters for determining the specific heat. The steam enters and leaves the two calorimeters through the glass tubes described above and passes directly over or around the thermo-couples for measuring the temperatures.

b A uniform supply of electrical energy at a constant voltage, and means for varying the amount of electrical energy between narrow limits. This has been obtained by the use of a motor generator set marked 8, Fig. 4 equipped with a Tirrel regulator marked 9, Fig. 4. The resistances used for controlling the amount of current, consist largely of incandesent lamps marked No. 10, Fig. 3 and 4. These have been used because they are not much affected by temperature changes in the room, currents of air, etc. The input of electrical energy is measured upon a single milli-volt-meter so arranged as to read both volts and amperes. This is done to avoid the errors in reading two separate instruments.

c Means for measuring absolutely the temperature of the steam entering and leaving the calorimeters. After an extended experience with the best mercurial thermometers obtainable in this country and abroad, we have found that the lack of constancy of the mercurial thermometer renders it totally unfit for this class of work. We are therefore measuring temperatures by thermo-junctions which are readily inserted in a desired posi-

tion and which we can calibrate with accuracy. We have tried platinum resistance thermometers but displaced them in favor of the thermo-couples.

d Means for eliminating the errors introduced by radiation of heat from the apparatus. This has been done as above described by arranging for equal radiation losses from the two instruments. To make sure that the radiation losses are the same from the two calorimeters special radiation runs are made by passing superheated steam through the calorimeters and introducing just enough electrical energy to equalize the entering and exit temperatures.

e Means for thermally isolating the apparatus and thus preventing loss of heat by conduction through pipe connections and supports. The pipe connections are the glass tubes described, and the supports are wooden blocks covered with Portland cement upon which the calorimeters rest.

f Means for obtaining a continuous measure of the amount of steam passing through the calorimeters; intermittent weighing of the condensed steam is not satisfactory. The continuous measure has been obtained by using the uniform diameter tubes containing the floats actuating needle points, or else fitted with small gage glasses in which the height of water can be accurately ascertained.

9 Observations made by the writer during the experiments, together with previous experience with steam calorimeters, led to the design of an electrically heated calorimeter for determining the quality of steam, and this calorimeter will now be described, as it is thought to be of especial interest in connection with steam-turbine practice.

CALORIMETER FOR DETERMINING THE QUALITY OF STEAM

10 Fig. 5 shows the exterior and the general interior arrangement of a steam calorimeter with which the quality of any steam passing through the calorimeter can be determined with accuracy in a very simple manner. The instrument is especially designed for determining the quality of steam at different points along steam turbines, and it can be used with steam of any degree of wetness and of any pressure above that in the condenser. The sampling

tube leading to the calorimeter may be extended into any steam passage from one part of the turbine to another to varying depths, and the average quality may thus be investigated. From this information, combined with the results of ordinary tests, a curve may be drawn on a heat diagram, showing the distribution of the work done by the steam in the turbine, and indicating the efficiency of the various sets of blades or buckets. Such a curve may also be used to indicate the degree of initial superheat that should be used in the entering steam in order that the steam at any set of blades may be in a given desired condition as to heat contents.

11 The development of the instrument resulted from experiments made by the writer in passing steam from an electrically heated calorimeter through a transparent glass tube. If the electrical energy supplied to the steam passing through the calorimeter was insufficient to dry the steam, the interior of the glass was clouded; also no rise of temperature was shown on a thermometer placed in the tube. By adding sufficient electrical energy to the steam, the interior of the tube cleared up at once, and the temperature began to rise at the same instant that the steam gave this evidence of being completely dry. It was therefore possible to measure directly the amount of heat required to dry the sample of steam, and from the known heat of vaporization of dry steam, and the known weight of steam passing through the calorimeter, the quality could be readily found,

12 In operation the calorimeter is attached to the turbine shell or other source of steam, by means of screw-thread *A*. The sampling tube, *B*, admits steam to the instrument, from which it passes to the condenser or to the atmosphere, through a pipe from the discharge valve, *C*. Having adjusted the discharge valve so it is passing a suitable quantity of steam, enough energy is turned in to heat the steam to dryness. The condition of dryness is indicated by an immediate rise of temperature, as shown by the thermometer, if more than the requisite amount of electrical energy is supplied. For convenience let the watts necessary to dry the steam be called E_1. After noting this number of watts, the steam is further heated by additional watts E_2, till a temperature T degrees above saturation is obtained; say 20 degrees or 30 degrees superheat. This operation is for the purpose of ascertaining the weight of dry steam per hour, W_1, which was passing when the steam was just dry. The weight, W_2, passed through the valve after superheating will be less than the dry steam passed through, by some percentage represented by a constant, C, because of the increase

in volume accompanying super[illegible]ing. This has been determined by tests with the instruments. Also, the watts S, necessary to superheat a pound of steam to T [illegible]grees, as different pressures, have been determined. The latter, S, may be used instead of the specific heat of steam, and has the advantage of allowing automatically for radiation losses. The quality of the steam may be obtained either by use of the curve supplied with the calorimeter, or by the use of the specific heat for varying pressures. The use of the curve, however, eliminates entirely any uncertainty of the value of the specific heat.

13 Let W_1 = weight of dry steam passing per hour.

Then E_1 watts evaporates the moisture in W_1 pound per hour, and this energy is equivalent to $\frac{3.42\ E_1}{W_1}$ thermal units per pound of steam. Let this amount of heat be represented by H_x. Let W_2 = weight of superheated steam passing per hour $= CW_1$. Then E_2 watts raises the temperature of CW_1 pounds of steam through T degrees, or $E_2 = CW_1S$ watts, where S represents the watts required to superheat one pound of steam per hour through T degrees, at the pressure in the calorimeter.

14 Then, $$W_1 = \frac{E_2}{CS}$$

and this value of W_1 may be substituted in the equation

$$H_x = \frac{3.42\ E_1}{W_1}$$

Thus, $$H_x = \frac{3.42\ E_1 \times CS}{E_2}$$

15 Since C and S are constants for any given pressure and degree of superheat, $3.42\ CS$ may be written as a constant, K, and values of this constant are given for varying pressures, by a curve supplied with the calorimeter.

The equation then becomes

$$H_x = K\ \frac{E_1}{E_2}$$

and if H_v represents the heat of vaporization of dry steam at the pressure indicated by the original temperature in the calorimeter, the quality of the steam passing through the calorimeter is

$$X = \frac{H_v - H_x}{H_v}$$

16 Summing up: to determine the quality of any steam passing through the instrument, introduce electrical energy until the thermometer just begins to show a rise of temperature. Note the watts, E_1, required. Then introduce further watts until a convenient degree of superheat has been reached, say 20 or 30 degrees. Note the watts, E_2, required.

17 From the curve select the value of K corresponding to the original temperature in the calorimeter and the degrees of superheat and find the thermal units from the equation,

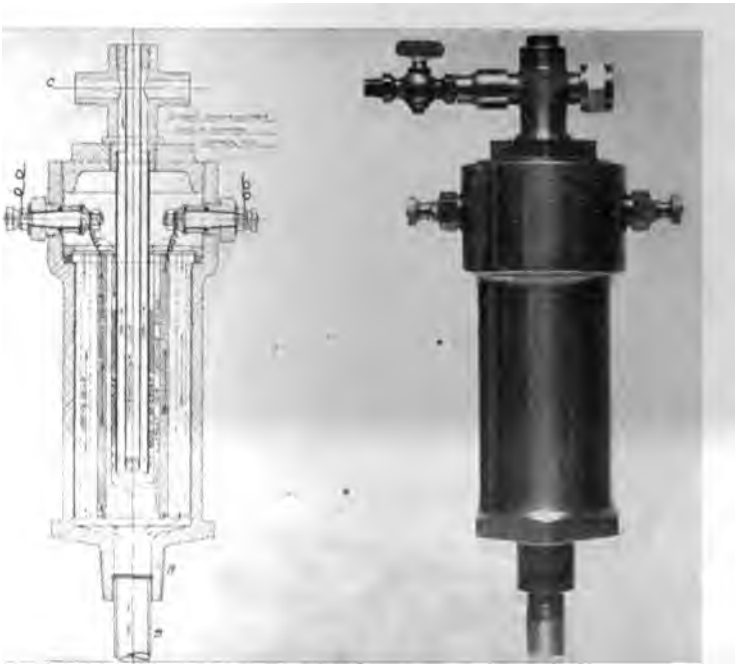


FIG. 5 DETAIL AND EXTERIOR OF STEAM CALORIMETER

$$H_x = K \frac{E_1}{E_2}$$

and the quality from the equation

$$x = \frac{H_v - H_x}{H_v}$$

18 For example: Let the steam pressure be 100 pounds abs., at which the heat of vaporization is 884 thermal units, and let the value of K be found from the curve to be 54.2

If the watt-meter readings give $E_1 = 240.$ and $E_2 = 93.0$

$$\text{then,} \quad H_x = 54.2 \left(\frac{240}{93}\right) = 140.$$

$$\text{and} \quad x = \frac{884 - 140}{884} = 0.84, \text{ or } 84 \text{ per cent.}$$

19 Curves giving values of x for varying pressures and values of H_x are supplied with the calorimeter.

MR. WARREN S. JOHNSON Professor Carpenter has read a very interesting paper, containing much information. In paragraph 7, he says that the plant used is an example of what may be accomplished on a small scale in the use of high pressure and a high degree of superheat in a steam engine, and is consequently of interest to the mechanical engineer irrespective of its special application to the propulsion of motor vehicles. Professor Carpenter's paper gives a more or less detailed description of the White power plant, the same being accompanied by illustrations. The paper, however, indicates plainly that there was no test of the White power plant as he says, but simply a theoretical test of the generator and engine.

2 It is hard to say why a description of the White power system, together with cuts, should be introduced in the paper, since the experiments were entirely on the efficiency of the boiler and of the engine, but entirely without the automatic regulation which is necessarily required to warrant calling it a system or a steam plant, as distinctive from other steam plants. The information as to the system, together with illustrations, is found in the literature of the manufacturing company.

3 Professor Carpenter's experiments consisted entirely of determining by experiments the value of superheated high pressure steam in small units, irrespective of the other appliances that are necessary to constitute a plant or system. It shows that what is true of the generator and the engine, as shown in these determinations, would be equally true of others, unless the White generator and engine have some special features that give it great efficiency over and above all others. If they have, it is very interesting and profitable for members of the Society to know that fact. If, however, these features are not pronounced, it appears to me that this fact should have been more clearly brought out in the paper.

4 The statement is made that the engine has no special features of merit, excepting its good workmanship. The generator or boiler has no special features that would give it greater efficiency than other

single tube water tube generators. The special feature in the generator consists of bringing the terminal of each horizontally disposed coil to the top and again descending to the next succeeding lower coil, this provision being used for the purpose of preventing the water which is forced in at the top from descending to the bottom, excepting through some exterior force. This provision has been used in previous boilers, and it will be readily seen that if any form of boiler of this character is sealed at the top—by a pump or otherwise—the water cannot descend, owing to the barometrical pressure, unless the coils are so disposed as to lie practically horizontally, in which case the steam might creep up and the water might run down.

5 The evaporative value of the generator, which was found to be 14.3 to 14.9 pounds of water to one pound of gasolene, is not remarkable when compared with the evaporative value of coal in ordinary fire tube boilers under forced draft, when the difference in the number of units in a pound of coal and a pound of gasolene is considered. If there is anything remarkable about it, it is that it has as great evaporative value as larger boilers have by the use of coal. The economy ought really to be greater, from the fact that the temperature of the flue gases was altogether too high. A single tube water tube boiler, in which the cold water is forced in at the top, has a great advantage in the way of abstracting valuable heat from the flue gases. It would seem, from the high temperature of the flue gases in this case, that there were not a sufficient number of horizontally disposed coils. The data given show that during the present season the cross section of the pipe or tube in the boiler has been raised seven-ninths of its former value. This greatly reduces the comparative friction and, therefore, indicates the use of a greater number of coils. I think that the restriction in the number of coils is one of convenience and to save space rather than to secure efficiency. During 1905, I made some tests on the evaporating value of a single tube water tube boiler, with differently arranged coils, and found that fifteen pounds of water were evaporated with one pound of fuel. This, you see, differs only one-tenth of a pound, as compared with the best results shown by Professor Carpenter, and indicates that the special features of the White generator cut no figure in the results. In either case the fire surface of the single tube water tube boiler is not as great as that of the ordinary automobile fire tube boiler, in which at least equally good results could have been obtained. Since there is nothing specially advantageous in the generator nor in the engine, the economy shown must necessarily be attributed to the high pressure and the superheated steam. Both of these elements have been found to be

extremely economical in much larger units, and many determinations have been previously made as to their economical valuation. If the intention of the paper was to indicate these high economies in automobile use, they certainly are misleading. While the relative economy of high pressure with superheat over low pressure with saturated steam would be as great in automobile use, the economy shown—both in the evaporation and pounds of water per horse power per hour—in practice would come nowhere near the results shown in this test.

6 In the first place, a compound engine does not show economy over a simple engine, excepting when it is run under a constant load. Even in locomotive use, on lines having grades, the compound engine shows no economy, as proved by the elaborate tests made by the Chicago, Milwaukee, and St. Paul Railway. If this be the case, what can be said when a compound engine is used in the very exacting work of automobile practice? The continual variations in the load continually change the output and the relations of the fuel to the evaporation. The repeated and often extinction of the fire, in order to secure unvarying temperature and pressure, will greatly reduce the economy in the use of fuel, and the high evaporation and small quantity of water used per horse power per hour will not be found.

7 It is regrettable that the test was not made with the apparatus as a whole, in what might be called a particular system, with all the varying conditions of load that develop in practice, so that the members of the Society could have gotten a more correct idea of the actual results. As the matter has been presented, it seems to me—as indicated in the beginning of my discussion—that the title is not really suggestive of what might be expected of the paper, and is quite liable to give a false impression as to the particular merits of the generator and engine.

THE AUTHOR I have read with a good deal of interest the discussion by Mr. Warren S. Johnson. I am not able, however, to agree with him in all particulars nor to look upon matters in every way from his standpoint.

2 The title of the paper "Steam Plant of the White Motor Car" is, it seems to me, fully indicative of the field covered. If the paper had been entitled "The White Motor Car" it would have been open to the criticism which Mr. Johnson makes. It is true that the paper relates to the construction and test of the steam plant of the White Motor Car, and furthermore that the test of the steam plant was made when the supporting framework was stationary. The conclusion cannot be

drawn from this fact that the economy of the steam plant for the same conditions of speed and load would be different were the car in motion, and I do not understand that Mr. Johnson makes any such claim, for it is evidently true that the economy would be the same were the steam plant mounted or stationary, provided the other conditions effecting efficiency, such as load and speed, were the same. I think, however, that the object which Mr. Johnson had in mind was to get on record such results as were accessible regarding the operation of the car.

3 It is quite evident that a road test of the car cannot give the fuel economy or efficiency of the steam plant based on definite units or units which are comparable in any way with those used for the measurement of power. A road test could give the fuel consumed per mile on level roads and in hill climbing, but this in turn is very much affected by the character and kind of the road, by personal management, by the condition of the tires, and by very many things which the makers of the vehicle cannot control. The results are also indefinite because of the varying quality of the surface of roads and the varying amount of power required for traction, and at best it can only give the results obtained in the paper reduced by the friction of the running gear. In another form Mr. Johnson may be said to criticise the paper for using a method of obtaining definite results instead of for using a method of obtaining indefinite results and results which, from a scientific standpoint, mean absolutely nothing. I know, however, that Mr. Johnson did not intend to have his statement interpreted in that manner, and that he desired to call the attention to the importance of road tests for a road motor car.

ROAD OR RUNNING TEST

4 Despite the indefiniteness of the results, a great deal of useful information in a comparative way is to be obtained from a road test, especially if a number of cars are made to pass over the same road and the conditions of loading and fuel consumption are carefully observed. At the time the test of the steam power plant, which is described in the paper, was made, this engine had not then been applied, except for a few preliminary runs, to a car, and consequently the data which he desires could not at that time be given.

5 Respecting this particular engine, in the 1907 car, I have the results of only one road test, and that test was made by Mr. Walter White in England. The general results of that test show the following: Distance traveled, 212 miles; time, 3 hours and 15 minutes;

gallons of gasolene, 23.5; weight of machi including fuel, 3490 pounds, number of passengers, 5; estimated weight of passengers, 800 pounds. Total weight carried, 4290 pounds.

6 There are numerous records of the performance of the 1906 car with an 18 horse power engine and of the 1905 car with a 16 horse-power engine. In the two gallon efficiency contest, which took place in New York early in 1906, a large number of gas engine cars and two White steam cars entered into the competition. The results of the trial of the 1906 White steam car were as follows:

No. of car	Weight loaded	No. of passengers	Miles on 2 gallons	Miles per gallon
53	3225	4	23.80	11.90
56	3370	5	22.51	11.26

7 I have made two road tests with a 1905 car. The first was conducted over the ordinary roads of eastern and central New York, during which the Catskill range of mountains was ascended and crossed. The car contained four passengers and luggage and had a total weight of 3020 pounds. The total mileage was 337 miles, the total amount of gasolene consumed was 33 gallons. This would indicate a mileage of 10.2 miles per gallon of gasolene. The average speed maintained for the entire distance was very nearly 18 miles per hour.

8 In a second test made with the same car with two passengers and with a total weight of 2680 pounds, I traveled a distance of 108 miles with a consumption of 8.1 gallons of gasolene. This corresponds to a distance of 13.3 miles per gallon. The latter test was made over an excellent road with very little gradient and with a rather better burner than that used in the first test which I made. The average speed during this last run was very nearly 21 miles per hour.

9 The above figures from road tests, while not very extensive, will probably be sufficient to give a good idea of the actual performance of the White motor car in conveying loads over different kinds of roads.

10 Mr. Johnson's statement that the test runs were not made under automatic control is not true; the automatic means were employed to quite as great an extent as in the motor car when on the road. The fuel supply was regulated during the tests entirely by the automatic thermostatic control as described. The water supply was controlled partly by hand during the test, as would be the case on a road test with the control means of the 1906 car. The statements in the paper respecting these conditions in the test show that the auto-

matic devices were used in practically the same way as in the operation of the car, although the hand control was used more for the reason that during the test it was necessary to maintain a uniform loading condition which is not material and which does not occur in driving a car over roads.

THE BOILER TEST

11 Mr. Johnson's statement that a flue temperature of 543 degrees F. is abnormally high for the best efficiency of steam boilers does not agree with my experience, nor does it agree, so far as I know, with the statements made in any reliable text-book on this subject. I do not believe that the addition of an extra tube to the boiler, which would have increased both its height and weight, would have added materially to its efficiency. The test figures on another boiler which Mr. Johnson gives, and which I understand had this additional heating surface, do not indicate any great gain over what was obtained with the cheaper and lighter boiler. It is not questioned that the addition of more heating surface would have given a slightly higher efficiency, but I do greatly question whether such efficiency would have been commercial and whether it would have been worth the expense required to obtain it. My own opinion is that a single tube boiler, which reduces the temperature of the flue gases to 300 degrees F., is unduly large for motor car construction. In fact I do not know of a stationary plant which would consider reduction of flue gases to 300 degrees F. as good practice.

12 Mr. Johnson refers to a method of calculating the thermal loss from the velocity of the flue gases. He does not state how such a calculation could be made if the velocity were known. Such a scheme would be extremely awkward if of any practical value whatever, and entirely unnecessary since the test which was made of the boiler obtained those thermal losses in a much better and more accurate way.

13 Respecting the advantages of the construction of the boiler itself over the one referred to by Mr. Johnson, I have nothing to say since I am not familiar with the construction to which he refers. It was not the object of this paper to compare one structure with another but merely to show the actual results in definite measures which certain structures produce.

14 Mr. Johnson states in effect that the generator of the White steam car does not represent a new system of producing and generating steam. He does not, however, state any references to earlier makes of boiler construction whereby the water could be fed into the

top of the boiler and the steam drawn off at the bottom in which the water was maintained at the upper level of the boiler by a system of bends or traps. I have spent some little time since his statement in looking up the history of this important invention, which has revolutionized the production and use of steam in the motor car industry, and I am not able to find that previous to White's invention in 1898 this construction was ever made or even suggested by anyone else.

15 It is very easy and very common to decry the importance of great inventions and also to give credit for their production to nameless inventors, and such statements frequently detract much from the reputation of an excellent invention. In this particular case it is very certain that White was the first to put into practical commercial use a boiler with the peculiar construction of his steam generator, and so far as I can learn he was also the originator of such a system for building and operating steam boilers. Boilers with a downward circulation of water built on different lines and working on different principles, some of which doubtless have considerable merit, have been described, but none of these boilers could produce the results which White obtained from his construction.

METHOD OF MAKING CAR TEST

16 Mr. Johnson suggests the making of a car test on a dynamometer in which I take it the rear wheels are intended to be supported by traction wheels which are connected to a Prony brake. Such a device is practicable and has recently been installed in Sibley College; this will give the friction of the various parts of the car and also its performance under different conditions as stated. It will not, however, give the efficiency of the engine and boiler, which was the object of the test. It would give a mixed result combined in an indefinite way of the power plant and running gear and is of little use as a reference. There are so few standards of comparison that the results called for by Mr. Johnson would at the present time be of little value except to motor car builders, but during the coming year our program includes the testing of a number of cars in such a manner.

ADVANTAGE OF THE COMPOUND ENGINE

17 The excellent results which were obtained in the test were doubtless due in great measure to the high degree of superheat and to the high pressure of steam. I do not believe, however, that results could have been obtained which approximated these if a simple instead of a compound engine had been used. Mr. Johnson points

out that a certain railroad has not found the compound locomotive as satisfactory as the simple engine; an investigation would also show him that certain other roads have found it more satisfactory. This merely tends to prove that we cannot decide whether a simple or compound engine is preferable from locomotive practice; as a matter of fact, the locomotive works under very different condition since its steam pressure rarely exceeds 200 pounds. It may be urged that as superheated steam prevents cylinder condensation, it does away with the gain due to compounding, but on the other hand it will be found that with as high steam pressures as 600 pounds per square inch it is nearly impossible to get sufficient expansion in the steam cylinder of a simple engine to give high economy. For that reason the compound will, in my opinion, give much more efficient results. It would be interesting, however, to test out a simple engine under the same conditions of steam pressure and superheat and compare it with the work done by the compound.

18 In marked contrast to Mr. Johnson's views I present a quotation from a letter by Mr. E. C. Walker, another builder of steam cars, who is designing a triple expansion engine:

> We have read with great interest in the December 19 issue of the "Horseless Age" the results of tests made by you of the steam power plant of the White automobile as set forth in a paper read at the December meeting of The American Society of Mechanical Engineers. We wish to congratulate you on the inestimable value of this work which you have conducted, and without hesitation will say that we consider this the most valuable paper on steam engineering, as applied to the motor car, that has ever been put in print.
>
> Do you think that the use of a triple expansion engine having cylinders of correct proportion, if used in combination with single tube boiler, or so-called flash boiler, would result in any marked degree of economy? Do you consider that the economy would justify the additional cost of manufacturing such an engine, and do you think that such economy would more than make up for the increase in weight of the engine, due to the addition of a third cylinder? We have been working in designing a triple expansion engine, intended for automobile service and to be used in combination with single tube boilers which we manufacture.

19 My reply to Mr. Walker encouraged him to expect greater economy, but it was not of a nature to give him any positive opinion as to the practical value of such an engine on a motor car.

20 The experience with the White compound engine has indicated that it had no practical disadvantages as compared with the simple engine, but that on the other hand it had many advantages, as it had proved not only more economical but it was more easily kept in repair and practically was superior from every standpoint.

21 In connection with this paper, attention should be called to a

paper by Mr. Thomas Clarkson on "Steam [illegible]ve Power for Public Service Vehicles," which was read at the November meeting of the Institution of Mechanical Engineers, England. Mr. Clarkson is a builder of steam cars for public service work; the paper referred to gives the details of his system of construction, and states the advantages which have resulted from its use, as compared with an internal combustion motor, and gives the costs of operation of certain cars in a public service for carrying passengers.

22 In the discussion of this paper by Col. Crompton, attention is called to the fact that Mr. White in his steam car has succeeded in getting nearer the internal combustion engine in regard to actual efficiency of fuel than anybody else with whose record he was acquainted.

23 Col. Crompton also states that he knew of White cars weighing 1¾ tons fully loaded that had been able to run at full speed with light loads 14 to 15 miles per (English) gallon of benzine. Respecting this performance he states:

> It was a new era in the use of steam. And the friends of that old and tried servant had now to take up the problem and work it out on the lines that had been followed so successfully.

24 Mr. Clarkson's vehicle is adapted to operate with kerosene oil, and a considerable portion of the discussion relates to the advantages and disadvantages of kerosene or, as the English call it, paraffin, as compared with gasolene or petrol.

25 The discussion by the chief inspector of the new Scotland Yard, Mr. Bossom, indicated that while paraffin had a much higher flash point, yet in practice it was actually more dangerous than petrol or gasolene. The statement was made and not denied that with paraffin the vehicle moved two miles per gallon while with "petrol" it moved seven miles per gallon.

26 The danger in the use of kerosene came from the light vapors driven off by the burner taking fire outside of the boiler structure. It was stated that while gasolene was much more volatile, in practice more precautions were taken in handling it and fewer accidents resulted. Another objection to the kerosene was the long time required to heat up, the great amount of smoke, and the bad smell.

27 The above statement is interesting as being quite contrary to the opinion held generally respecting the use of kerosene as a fuel. The particular danger it was claimed came from the fact that the kerosene was greatly heated before it entered the burner, which rendered it anything but a safe fuel.

CONTROL OF THE 1907 CAR

28 Since the paper was written, a new system of automatic control for the supply of steam and water has been adopted and put in use on the White steam car. In the new system of control a constant steam pressure is maintained on the boiler regardless of the conditions of the load. The hand by-pass for the feed water has been removed and practically the only thing required of the operator is to steer. In the new system the feed of fuel is controlled by the action of a thermostat on a motor operated by the pump and termed a flow regulator. The water is controlled by a pressure regulator as in the old system

29 Whenever the steam pressure exceeds the normal working pressure, say 600 pounds per square inch, the water regulator opens a by-pass valve and diverts from the generator the stream of water from the pumps. When the steam pressure falls below 600 pounds, the regulator again acts, closing the by-pass valve, and the water from the pumps is again directed to the generator. The regulating system up to this point is identical with that used on White cars for the last six years.

30 From the pumps there are two separate and distinct paths by which the water may reach the generator, either through or around the "flow-regulator."

31 The flow-regulator, A_4, is a compact and simple motor operated by the pump which may be said to have two distinct functions. Its first function is to open and close the supply of gasolene to the burner, which it does in this fashion; when water is passing through the flow-regulator, the water forced in by the pump moves a piston, against the action of a spring, and the motion of this piston is utilized to open a valve B_2 in the gasolene line. When water stops passing through the flow-regulator (which will happen whenever the engine stops or whenever the pressure exceeds 600 pounds), the piston is no longer under pressure and the action of the spring returns it to its original position, this motion serving to close the valve in the gasolene line, thus shutting off the supply of fuel to the burner. Second, it is so constructed that it will permit only a definite quantity of water to pass through it, any excess being returned through a by-pass valve to the water tank.

32 The accompanying diagram of the new control system, which is merely a modification of the old one described in the paper, may make its mode of operation clear. In the diagram, A_1 is the pump, A_6 the generator, A the water tank, A_4 the flow regulator or motor, B_2 the fuel valve, A_5 the thermostat, A_3 the water regulator.

33 The water regulator A_2 is operated by pressure to turn on or off a by-pass pipe leading back to the water tank. If the steam pressure exceeds 600 pounds, the by-pass valve is opened and the water returns to the water tank; if in excess of that, it is closed, and the entire water delivered by the pumps is forced toward the generator. The feed water line has two branches, one flowing through the thermostat A_5, the other through the motor or flow regulator A_4, which branches unite again before reaching the generator. The branch leading through the thermostat has its flow controlled by a valve which is opened or closed by the thermostat and which acts by the temperature of the steam. If the temperature of the steam is too low, the thermostat serves to close the passage to the branch around the flow regulator and divert it into the flow regulator; this causes more pressure to act to move the piston in the flow regulator a greater distance which, in turn, opens up the fuel valve B_2, and lets on more fuel. If the piston in the flow regulator moves too great a distance, it opens a by-pass valve in pipe A_7, and allows the excess water to return to the water tank and prevents flooding of the boiler. If the temperature rises, the reverse operation takes place and the fuel is closed off. The new regulator differs from the old one in this way, that whereas in the old system, the thermostat controlled the fuel valve directly, in the new system it controls it indirectly through a motor, thus giving it a greater range of motion in a more positive manner.

GENERAL ADVANTAGES OF STEAM CARS

34 If an amount of steam greater than that which corresponds to the water coming to the generator is drawn off, the steam pressure will, under these circumstances, tend to fall off and the temperature of the steam in the generator will tend to rise above the normal, because the fire will remain "on" since, as has already been stated, the capacity of the burner is in excess of that necessary to evaporate the water going into the generator by way of the flow regulator; as soon as the temperature of the steam exceeds the normal, the thermostat acts, opening a valve which permits water to be diverted from the flow regulator or motor, thus closing the fuel valve. Under these conditions the temperature and pressure immediately become normal and the thermostat again acts, shutting off the auxiliary water supply.

35 I have been asked several questions respecting the advantages which steam possesses as motive power for cars. This consideration has not formed any part of my paper and it is evident to any person who considers the subject that each and every kind of power will

possess peculiar advantages for certain conditions or for certain demands.

36 In an article published in the "Review of Reviews," January, 1907, by Harry D. Haines, the following statement, which will, I think, be generally concurred in, is made respecting the steam machine.

> The steam machine has these advantages: little jar or noise, ease of control, and simplicity in operation, inasmuch as a single throttle controls all speeds, and thus a more elastic power is secured. Gears are eliminated and so is the possibility of putting the car out of commission by stripping them. The steam car, with its direct drive, makes possible greater simplicity of construction and a reduction of repair bills in the absence of ignition systems and their troubles, as well as the further absence of "overheating" and the troubles due to carbonization of lubricating oils in gas engines. Steam is a known power and is more generally understood and more easily repaired when out of order. The bugaboo of burned out boilers and other boiler troubles has been eliminated by the use of the flash boiler, and all adjustments and regulations are now automatic, depending only on varying temperature and pressure. In a steam car wear and tear on the machinery is saved by the fact that the engine never races and does not run when the car is standing still. The engine has greater elasticity, inasmuch as it is possible to increase steam pressure and the consequent power enormously when bad hills or roads are met with, giving a valuable reserve power. The absence of smoky exhausts, of "back firings" of dirty motors, and the noises of worn ones are claimed as advantages for the steam car, as is the fact that the cost of fuel consumption is proportionate to the power developed. As a final clincher the cheapness in first cost is added.
>
> On the other hand, the steam machine requires time to be got ready for road work in waiting to get up pressure. The need of extinguishing the fire when the car is stopped for any length of time and relighting it again is quoted against the steam car, but this to a great extent has been overcome by improved burners and pilot lights. The limited water and fuel capacity, increased gasolene consumption, and the trouble from clogging of valves or failure of pumps are also considered disadvantages, and it is further maintained that the results of neglect are more serious in a steam car, and that the necessity of using soft water at times causes annoyance, as does the freezing of pipes in cold weather. Last but not least, many people are influenced by the greater danger of the destruction of the car by fire in case of accident. This is in reality the greatest argument against the steam machine, for if the car is involved in a smash-up, or is ditched, the gasolene feed-pipe is apt to be broken and then the gasolene ignites from the burner.

37 Respecting the disadvantages which are stated, the one in regard to the use of soft water I have found does not occur with the White steam car. No difficulty whatever has been experienced due to boiler scale or even to oil in the water, which fact I have already referred to in the body of the paper. I have also found no disadvantages resulting from limited water or fuel capacity, nor has any trouble been experienced due to the clogging of valves or failure of pumps.

The White car which I have been operating has water and fuel capacity sufficient for 150 miles, which is practically the same as that of most of the gasolene cars. There has also been no trouble experienced from increased gasolene consumption which, on the whole, does not seem to average in practice much greater than that of gasolene cars with the same carrying capacity, and is more than offset by the smaller bills which require to be paid for tires.

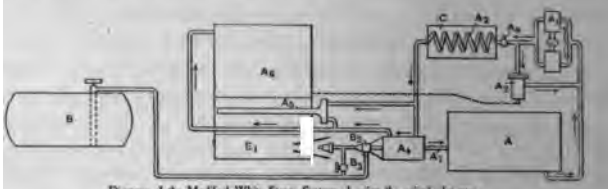


Diagram of the Modified White Steam System, showing the principal water and fuel connections, together with the automatic control devices.

A. Water Tank.
A1. Pumps.
A2. Water-regulator.
A3. Coil in Feed-water Heater.
A4. Flow Regulator.
A5. Thermostat.
A6. Generator.
B. Fuel Tank.
B2. Fuel Valve.
B3. Hand Valve for starting.
E1. Burner.

FIG. 1 DIAGRAM SHOWING THE NEW CONTROL SYSTEM FOR THE SUPPLY OF STEAM AND WATER

38 I agree with Mr. Haines that the greatest argument against the steam car is the danger from the open gasolene flame in case of accident. This danger in the 1907 White car has been greatly reduced by the heavy construction of pipe and gasolene tank, by entirely enclosing the pilot lamp, and building it generally in such a manner that the gasolene pipe or tank could not be ruptured by an accident, and by special features which confine the flame under all conditions to the burner. Considering the number of these cars in use, the accident from the open flame has been very rare and except in a few cases has generally been due to gross carelessness on the part of the operator or those handling gasolene.

No. 1128

TEST OF A PLUNGER ELEVATOR PLANT

By ARTHUR J. HERSCHMANN, NEW YORK, N. Y.
Member of the Society

1 The tests to which the appended tables refer are commercial tests made on the plunger elevator plant of the Trinity Building, New York City, while in regular operation. It was not thought that the accuracy of the results would be materially improved by resorting to greater elaboration in preparing for the test, or in the manner of conducting the same. On the other hand, it was held that with the plan adopted data would be obtained which would enable the plant to be readily compared with those of other buildings while in regular operation and such data should, on account of the peculiarity of elevator service in an office building, more correctly define actual economy than the results obtained from a dead load test in which intermittency of service would not be the same as in the ordinary running of an elevator plant.

2 It will be seen that two series of tests are tabulated. In the first, September 7, a duplex compound pump was used, and in the second, September 8, a high duty fly wheel pump.

3 With the use of the auxiliary steam line it was possible to run the elevator pump on a separate boiler of 350 horse power, steam for the remainder of the plant as well as for all boiler feeding being supplied each day by a boiler of 265 horse power.

4 It should be noted that, roughly speaking, boilers and pumps were run at about half load so that with a heavier traffic the economy should be further improved.

5 The five high rise elevators discharge into auxiliary tanks from which water is supplied to the cylinder through an automatic valve when the pressure water is shut off on the up trip. This system saves about 5 per cent of the plunger displacement in high pressure water.

6 Approximate figures are given for the water evaporated by the boilers, but any error in these figures does not affect the results obtained for the economy, which are based on the amount of coal burned. The water was measured by a meter which was not calibrated during

Presented at the New York Meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

or after the tests. The meter was, however, calibrated by the maker before the tests and found to be substantially correct, so that it is

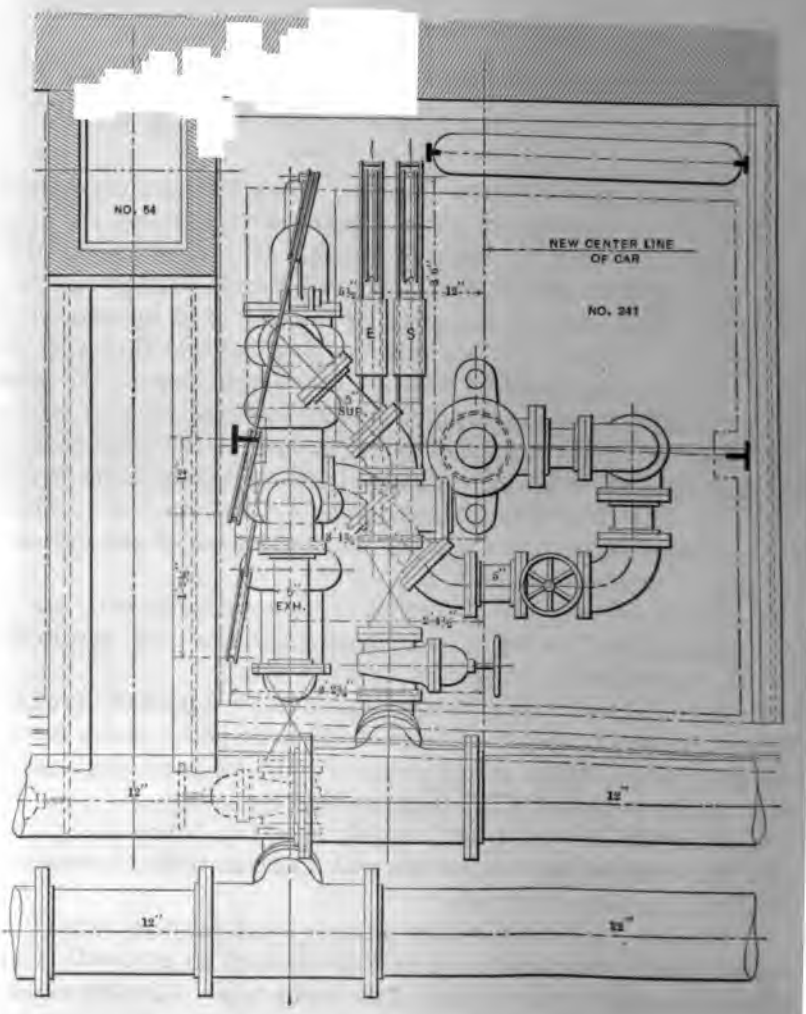


FIG. 1 PLAN OF ELEVATOR SHOWING CONTROLLING VALVE AND AUTOMATIC STOP OPERATING MECHANISM

believed that the figures for evaporation cannot be very much in error. All figures depending on the reading of the meter are marked "approximate" in the tables.

7 It will be seen that the cost of coal per car mile was 5.22 cents with the fly wheel pump, and 8.04 cents with the compound duplex pump.

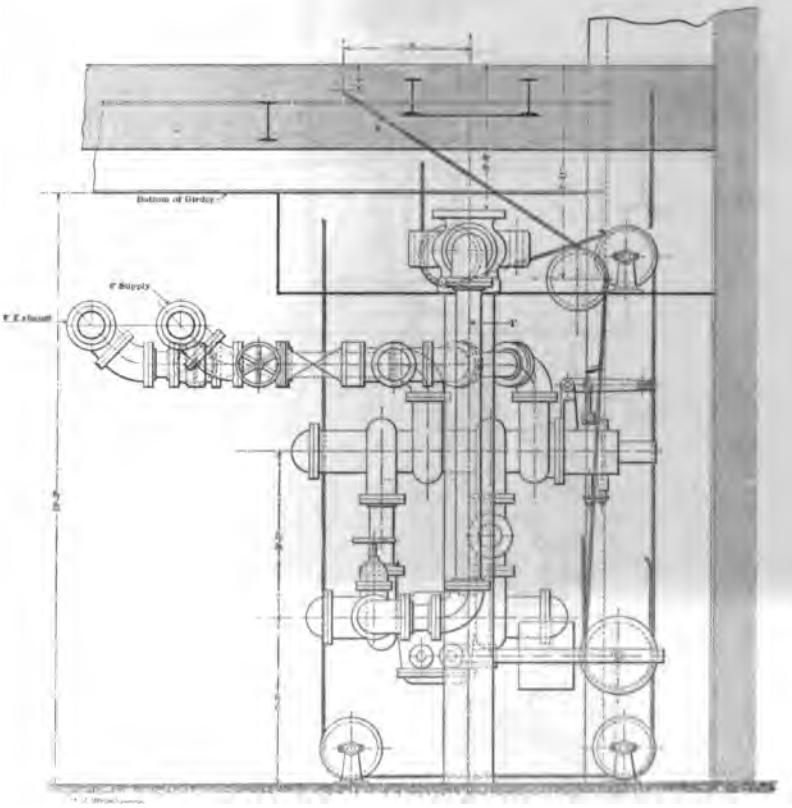


FIG. 2 ELEVATION OF ELEVATORS SHOWING CONTROLLING VALVE AND AUTOMATIC STOP

8 Costs are figured for the service referred to, including necessary losses, such as leakage, slip, and water consumed by pilots and motor valves.

9 Thanks are due to Mr. F. E. Glass and Mr. Noble C. Butler, Jr., who have assisted me in conducting the above tests, also to Chief Engineer Thure Larssen of the Plunger Elevator Company for drawings and data supplied for publication before the Society.

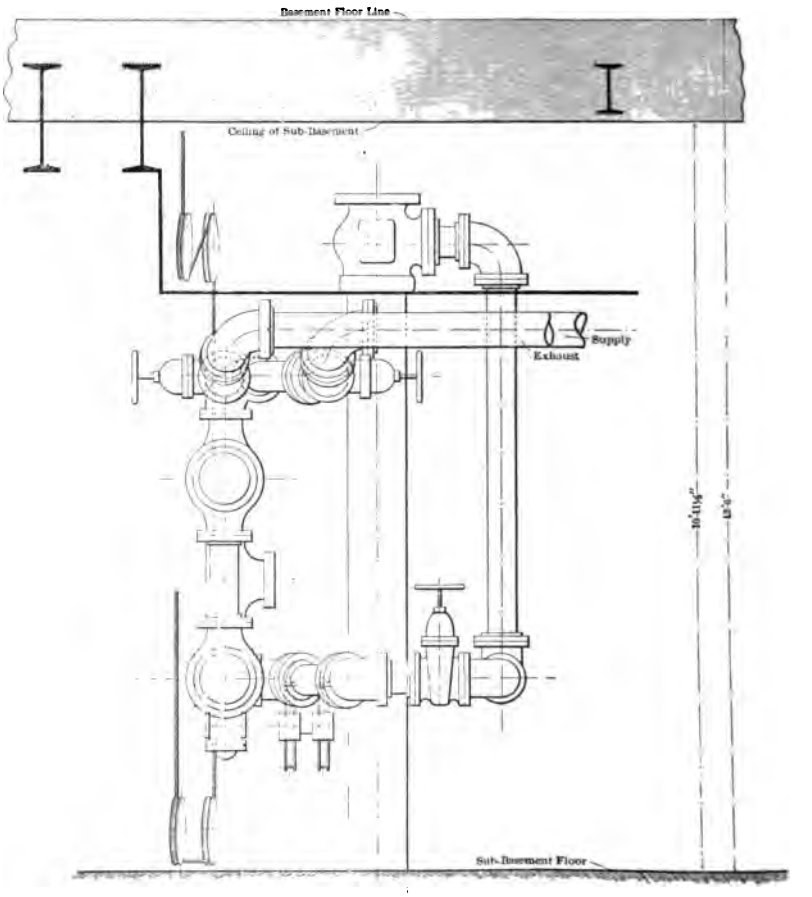


FIG 3 ELEVATION SHOWING PIPING CONNECTIONS

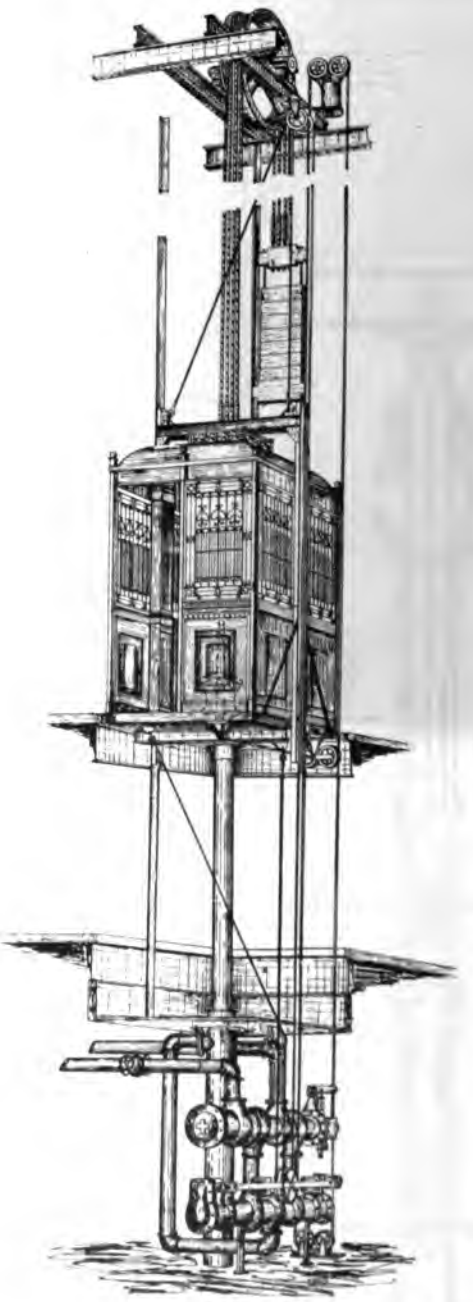


FIG. 4

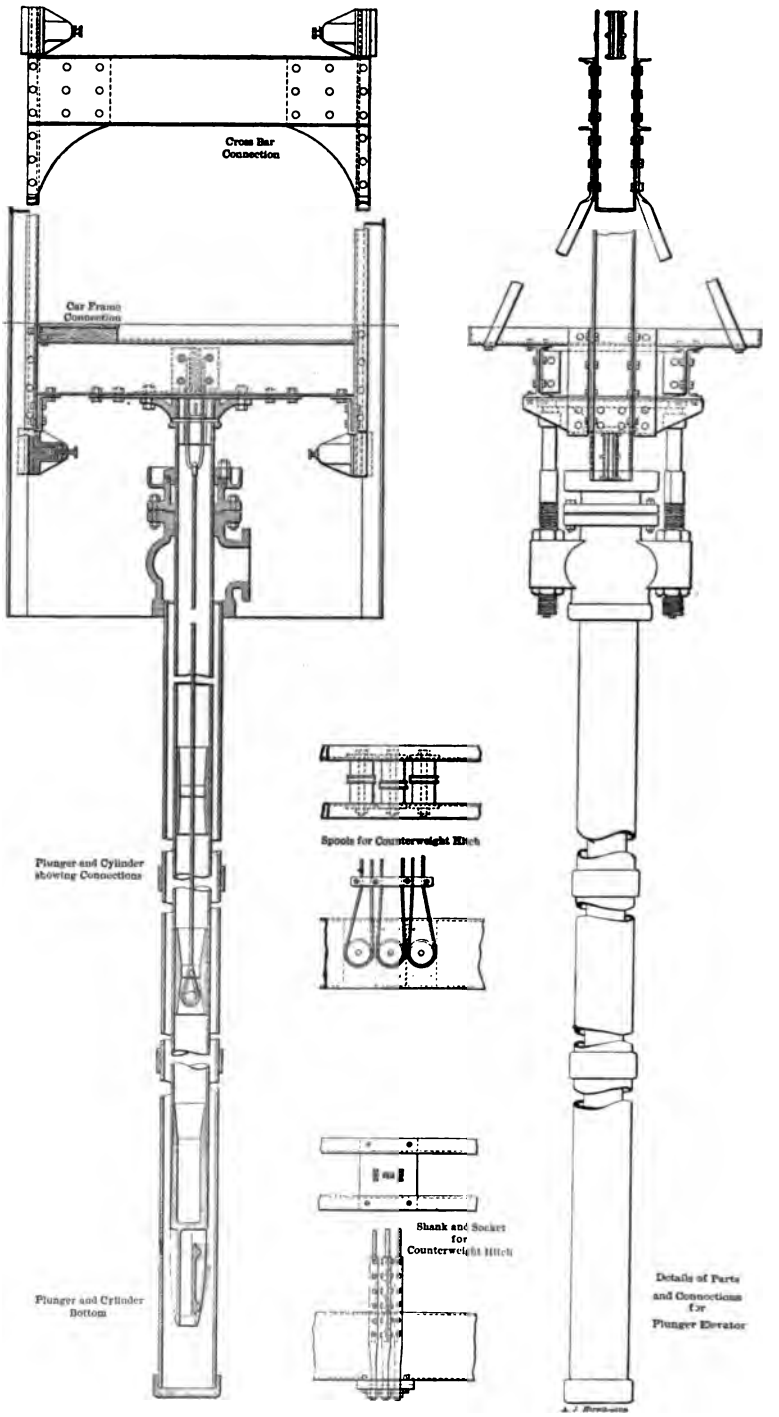


FIG. 5 DETAILS OF PARTS AND CONNECTIONS FOR PLUNGER ELEVATOR

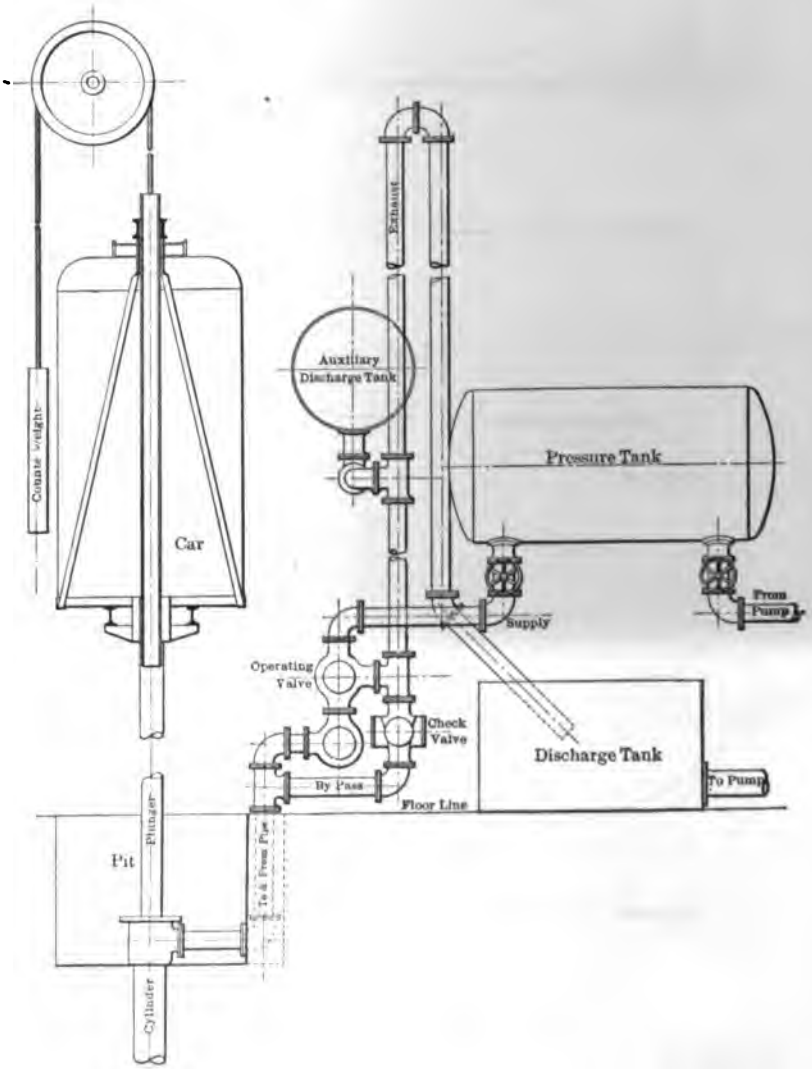


FIG. 6 TYPICAL PIPING DIAGRAM SHOWING BACK PRESSURE SYSTEM

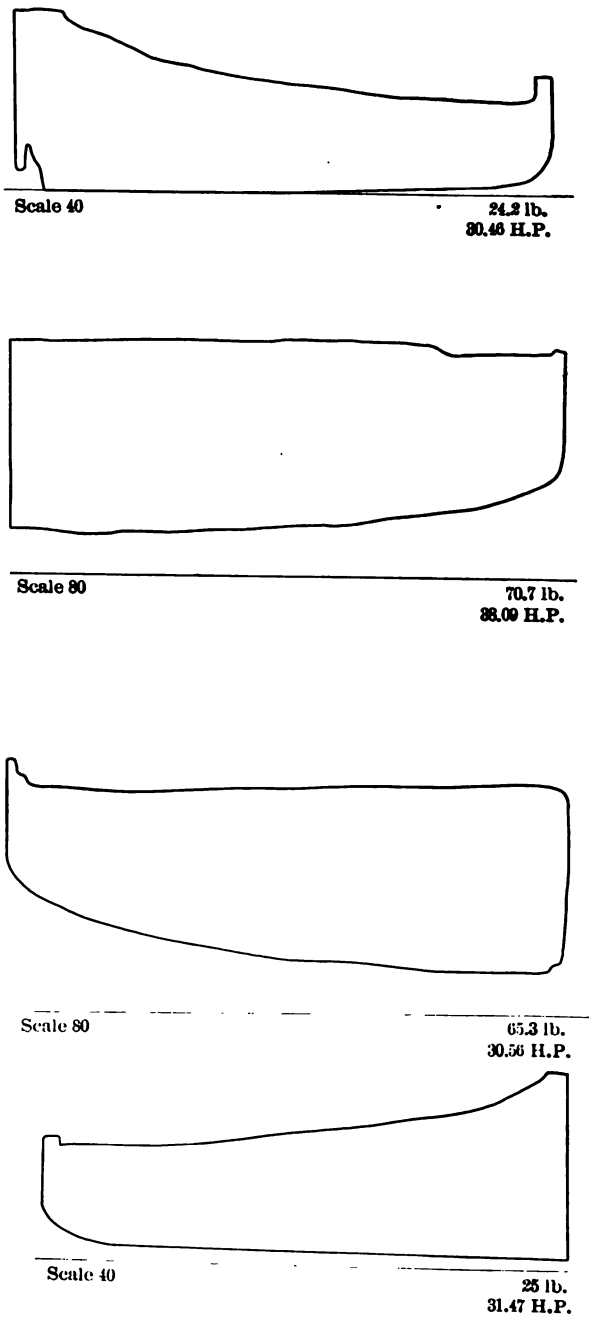
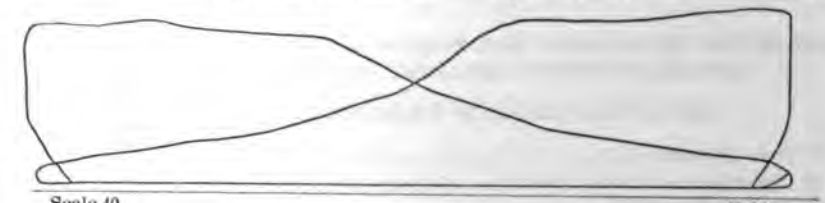
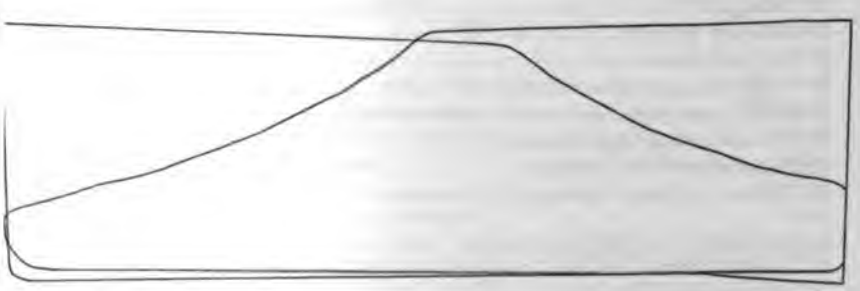


FIG. 7 INDICATOR CARDS OF WORTHINGTON DUPLEX COMPOUND PUMPS
TIME 2:45 P. M., SEPTEMBER 7, 1905



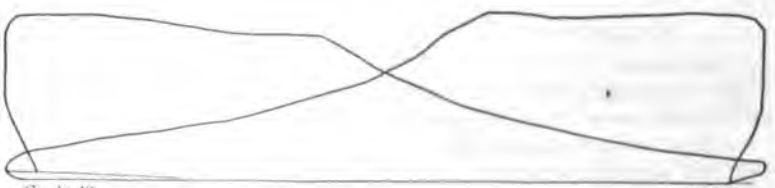
Scale 40

20.2 lb.
29.5 H.P.



Scale 80

79 lb.
73.07 H.P.



Scale 40

20.3 lb.
29.7 H.P.

FIG. 8 INDICATOR CARDS OF LAIDLAW, DUNN, GORDON FLYWHEEL PUMPS
TIME 3:30 P. M., SEPTEMBER 8, 1905

BOILER TEST TO DETERMINE COAL USED BY [illegible] SYSTEM AND THE APPROXIMATE WATER EVAPORATED. DUPLEX COMPOUND PUMP

Test on No. 3 *Babcock & Wilcox* 350 *horse power Boiler*

1 Date of test	September 7, 1905
2 Duration	9 hours, from 8.30 a. m. to 5.30 p. m.
3 A heating surface and grate	3808 and 75.8 sq ft.
4 Fuel	Buckwheat No. 1; $3.40 long ton (11,650 B. t. u.)
5 Steam pressure above atmosphere	maximum, 150; minimum, 140 average, 141 lbs. per sq. in.
6 Draught	Chimney, 1.25; at fire door 0.6 in.
7 Feed water temperature	maximum, 208; minimum, 208 (208 at heater) deg.F.
8 Depth of fire	4 ins.
9 Coal burned	7000 lbs.
10 Coal burned per hour	average, 777 lbs.
11 Ashes	1300 pounds, or 19 per cent of dry coal
12 Moisture in coal	2½ per cent
13 Dry coal burned	6825 lbs.
14 Water evaporated as registered by meter	5490 gal.
15 Boiler horse power developed (approximate)	148.9
16 Per cent rating (approximate)	42½ per cent average
17 Dry coal per hour, average	758 lbs.
18 Number of people going up in elevators	4495

BOILER TEST TO DETERMINE THE COAL USED BY ALL PARTS OF THE PLANT, WITH THE EXCEPTION OF THE ELEVATOR SYSTEM, AND THE APPROXIMATE WATER EVAPORATED

Test on No. 1 *Babcock & Wilcox* 265 *horse power Boiler*

1 Date of test	September 7, 1905
2 Duration	9 hours, from 8.30 a. m. to 5.30 p. m.
3 Heating surface and grate	2932 and 59½ sq. ft.
4 Fuel	Buckwheat No. 1; $3.40 long ton (11,650 B. t. u.)
5 Steam pressure above atmosphere	maximum, 150; minimum 140 average, 142 lbs. per sq. in.
6 Draught	Chimney, 1.25 ins. at fire door 0.6 in. lbs. per sq. in.
7 Feed water temperature	maximum, 208; minimum, 208 (208 at heater) deg.F.
8 Depth of Fire	4 ins.
9 Coal burned	6100 lbs.
10 Coal burned per hour	average, 677 lbs.
11 Ashes	910 lbs, or 15 per cent of dry coal
12 Moisture in coal	2½ per cent
13 Dry coal burned	5948 lbs.
14 Water evaporated as registered by meter	6344 gal.
15 Boiler horse power developed (approximate)	172.2
16 Per cent of rating (approximate.)	65 per cent average
17 Dry coal per hour, average	661 lbs
18 Ampères	maximum, 700; minimum, 350; average 509
19 Kilowatt hours generated during test	550, at 1.68 cents for coal

(50 Kw. General Electric Marine Type)

BOILER TEST TO DETERMINE THE COAL USED BY THE ELEVATOR SYSTEM AND THE APPROXIMATE EVAPORATION. FLY WHEEL PUMP IN USE

Test on No. 3, Babcock & Wilcox 350 horse power Boiler

1	Date of test	September 8, 1905
2	Duration	9 hours, from 8 a. m. to 5 p. m.
3	Heating surface and grate	3,808 and 75.8 sq. ft.
4	Fuel	Buckwheat No. 1 (11,650 B. t. u.)
5	Steam pressure above atmosphere	maximum, 145; minimum, 140 average 144 lbs. per sq. in.
6	Draught	Chimney, 1.25 in.; at fire door 0.6 in.
7	Feed Water temperature	maximum, 206; minimum, 185; average 195 (208 heater) deg. F.
8	Depth of fire	4 ins.
9	Coal burned	4400 lbs.
10	Coal burned per hour	average 489 lbs.
11	Ashes	750 lbs, or 17 per cent of dry coal
12	Moisture in coal	2½ per cent
13	Dry coal burned	4290 lbs.
14	Water evaporated as registered by meter	3800 gal.
15	Boiler horse-power developed (approximate)	104.05
16	Per cent of rating (approximate)	30 per cent average
17	Dry coal per hour, average	476 lbs.
18	Number of people going up in elevators	5040

BOILER TEST TO DETERMINE THE COAL USED BY ALL PARTS OF THE PLANT WITH THE EXCEPTION OF THE ELEVATOR SYSTEM AND THE APPROXIMATE WATER EVAPORATED

Evaporative Test on No. 1, Babcock & Wilcox 265 horse power Boiler

1	Date of test	September 8, 1905
2	Duration	9 hour, from 8 a. m. to 5 p. m.
3	Heating surface and grate	2932 and 59½ sq. ft. (265 horse power rated.)
4	Fuel	No. 1 Buckwheat (11,650 B. t. u.)
5	Steam pressure above atmosphere	maximum, 145; minimum, 140 average, 144 lbs. per sq. in.
6	Draught	Chimney, 1.25; at fire door 0.6 in.
7	Feed water temperature	maximum 206, minimum, 198 average, 201 (208 Heater) deg. F.
8	Depth of fire	4 ins.
9	Coal burned	5800 lbs.
10	Coal burned per hour	Average 644 lbs.
11	Ashes	875 lbs. or 15 per cent of dry coal
12	Moisture in coal	2½ per cent
13	Coal burned dry	5645 lbs.
14	Water evaporated as registered by meter	6370 gal.
15	Boiler horse power developed	177
16	Per cent of rating (approximate)	67 per cent average
17	Dry coal per hour, average	628 lbs.
18	Ampères	maximum, 600; minimum, 300; average, 413
19	Kilowatt hours generated during test	446 at 1.96 cents for coal

TESTS OF TRINITY BUILDING ELEVATORS

No. 3 Express load of 1617 pounds in car, Basement to 21st floor. Up in 43 seconds. Average speed 393 feet per minute, highest 438. Down in 27 seconds. Speed, 629 feet per minute.

Overrunning Test

Load of 1617 pounds in car up, 12 feet 4 inches; lost 8 seconds. Speed 490 feet at 11th floor overrun.

Down, 14 feet; lost 9 seconds. Speed 540 at 11th floor overrun.

Basement to 21st floor:

Load of 1617 pounds in car. 6 stops. Up, 1 minute, 25 seconds; repeated, 1 minute, 17 seconds.

Down *1 minute, 8 seconds; repeated, 1 minute, 25 seconds.*

Trips in 2 minutes, 33 seconds; 2 minutes, 42 seconds, respectively.

First floor to 21st floor: stops at 11, 13, 15, 17, 19, 21st floors. *Up, 1 minute, 9 seconds.* Stops at 20, 18, 17, 15, 12, 11th floors. *Down, 1 minute, 1 second.*

Round trip in 2 minutes, 10 seconds. Water pressure, 170 lbs. per sq. in.

CONDITIONS

Stops must be no more than 3 inches out of level.
Open and shut door at each stop.
Stops ordered after door was shut.

Load of 1617 pounds in car up, 1st to 21st floor, stops at 12, 13, 16, 18, 20, 21st floors; *1 minute, 10 seconds.*
Down 21st to 1st floor, stops at 19, 17, 15, 13, 12, 11, 1st, *1 minute, 6 seconds.*
Round trip in 2 minutes, 16 seconds. Water pressure 165 to 185 lbs. per sq. in.

Up 1st to 21st, stops at 11, 13, 15, 17, 19, 21st, *1 minute, 10 seconds.*
Down 21st to 1st, stops at 20, 18, 16, 14, 13, 11, 1st, *1 minute, 4 seconds.*
Round trip in 2 minutes, 14 seconds. Water pressure 165 to 185 lbs. per sq. inch.
Generally excellent stops.

TESTS OF TRINITY BUILDING ELEVATORS

No. 3 express, load of 1617 pounds in car.
Speed, flying test, up 3d to 11th floor; speed 490 ft. per minute.
Water pressure, 180 lbs. per sq. in.
Overruning test, up load of 1617 lbs.
Flying test, 3d to 11th floor; speed, 490 feet per minute.
Overrun, 12 feet 4 in; lost time, 8½ seconds.
Overruning test, down. Load of 1617 lbs. in car.
Flying test, 11th to 3d floor, speed, 540 feet per minute.
Overrun, 14 feet; lost time, 9 seconds.

As seen above, an express elevator of the Trinity Building made the round trip—1st to 21st floor—with 1617 lbs of load, stopping 6 times each way, in 2 minutes and 14 seconds. Doors were opened and shut, good stops insisted on, and no advance orders given.

Express No. 3, load of 1756 pounds in car. Water pressure 185 lbs. per sq. in.

Basement to 3d floor, 10 seconds, speed 279 feet; 3d to 11th, 15 seconds, speed 420 feet.

Up, at a speed of 420 feet, overran 11 feet 6 inches, lost 7 seconds, repeated, overran 10 ft. 6 inches, lost 9 seconds.

Down, 21st to 18th floor, 7 seconds, speed 325 feet; 18th to 11th floor, 6 seconds, speed 885 ft; 11th to 3d floor 14 seconds, speed 450 feet.

Same car load of 1915 pounds in car. Water pressure, 190 lbs. per sq. in.

Up, basement to 21st floor. Highest speed 11th to 18th floor, 531 feet, average 41 seconds, 412 feet.

Down, 21st floor to basement. Highest speed, 18th to 11th floor, 885 feet, average 28 seconds, 600 feet.

Best result overrunning going up 9 feet on 11th floor at 468 foot speed; least time lost, 7 seconds.

Local No. 5, load 653½ lbs. in car. Water pressure 185 lbs. per sq. in.

Up, highest speed 3d to 11th floor, 636 feet, average, 35 seconds 480 feet; repeated with same result.

Down, 21st floor to basement. Highest speed 18th to 11th floor, 590 feet, average 35 seconds, 480 feet.

Local No. 8, four men, load of 653½ pounds in car. Water pressure 185 lbs. per sq. in.

Up, basement to 11th floor. Highest speed 3d to 8th floor, 456 feet, best average, 24 seconds 388 feet.

Down, 11th floor to basement. Highest speed 8th to 3d floor, 411 feet, average 28 seconds or 330 feet; repeated with same result.

Local No. 9 same load. Water pressure 185 lbs. per sq. in.

Up, basement to 11th floor. Highest speed, 3d to 8th floor, 587 feet, best average, automatic, 17 seconds, speed 548 feet.

Down. 11th floor to basement. Highest speed, 8th to 3d floor, 373 feet, best average, 29 seconds, 322 feet.

Local No. 10 same load. Water pressure 185 lbs. per sq. in.

Up, basement to 11th floor. Highest speed; 3d to 8th floor, speed 456 feet, average, 22 seconds or 420 feet.

Down, 11th floor to basement. Highest speed 3d floor to basement 370 feet, average, 30 seconds or 310 feet.

Heights of Floors, Trinity Building

Sub-basement	12 feet 6 inches
Basement	13 feet 6 inches
1st	19 feet 6 inches
2d	16 feet 6 inches
3d to 5th, inclusive	14 feet 6 inches
6th to 16th, inclusive	14 feet 6 inches
17th	13 feet 6 inches
18th	13 feet
19th and 20th	12 feet 6 inches
21st	11 feet

Elevator Travels

Basement to 3d	49½
Basement to 21st	282
Sub-basement to 21st	294½
3d to 8th	68½
3d to 11th	106
2d to 11th	122½
2d to 18th	211
8th to 11th	37½
11th to 18th	88½
18th to 21st	38

ECONOMY TEST OF ELEVATOR SYSTEM WITH DUPLEX COMPOUND PUMP IN USE

September 7, 1905

Record of Data

1 Horse power developed by boiler (approximate).....148.9 average
2 Coal burned in the 9 hours .....7,000 lbs.
3 Quality and cost of coal.....Buckwheat, No. 1; $3.40 long ton
4 Calorific test of coal.....(75.04 fixed carbon; 11,650 B. t. u.)
5 Moisture in coal .....2½ per cent
6 Ashes in pounds 1300
7 Ashes, per cent of dry coal.....19
8 Evaporation per lb. of coal (approximate.) 6.29
9 Coal, pounds per car mile 53
10 Coal, pounds per kw. h., including house service and all boiler feed.....11
11 Coal, cost per car mile.....8.04 cents
12 Coal, cost per lamp including house service 0.084
13 Coal, cost per kw. h. including house service.....1.68
14 Round trips made by locals, 848—1st to 11th floor—142 feet.
8—Basement to 11th floor—155 ft.
Total distance traveled in one direction, 121,660 feet.
15 Round trips made by express, 793—1st to 21st floor—268.5 ft.
47—Basement to 21st floor—282 feet.
Total distance traveled in one direction, 226,174 ft.
16 Number of feet traveled in one direction, or ½ total travel for day of 9 hours.....347,834
17 Total number feet per hour traveled in both directions.....77,296
18 Average number of car miles per hour.....14.63
19 Elevator fuel per hour, 777 lbs., costing.....1.18
20 Cost of electric and house pump fuel per hour.....1.03
21 Indicated pump horse power (mean of cards) 126.19
22 Mechanical efficiency of pump, per cent.....0.927
23 Water horse power delivered by pumps.....117.9
24 Steam used per mile car travel, lbs. (approximate).....350.5
25 Coal used per mile car travel, lbs.....53
26 Car miles for day of 9 hours.....131.74
27 Pump used.....Henry R. Worthington Duplex Compound, 21x34x18x24
28 Revolutions in 9 hours.....6473
29 Revolutions per minute.....12
30 Slip total, per cent.....4.3
31 Water delivered per revolution, actual in gallons.....99
32 Number of passengers in 9 hours (4495). Round number.....4500
33 Cost of coal per passenger lifted .....0.24 cent
34 Water horse power per car mile 8
35 Actual water pumped, gallons 640,827
36 Average water pressure during day in pounds per sq. in.....176

ECONOMY TEST OF ELEVATOR SYSTEM WITH FLY WHEEL PUMP IN USE

September 8, 1905

Record of Data

1 Horse-power developed by boiler (approximate) ..... 104.05 average
2 Coal burned in the 9 hours ..... 4400 lbs.
3 Quality and cost of coal ..... Buckwheat, No. 1; $3.40 long ton
4 Calorific test of coal ..... 75.04 fixed carbon; (11,650 B. t. u.)
5 Moisture in coal ..... 2½ per cent
6 Ashes in pounds 750
7 Ashes per cent of dry coal 17
8 Evaporation per pound of coal (approximate) 6.93
9 Coal, pounds per car mile 34.4
10 Coal, pounds per kw. h. including house service and all boiler feed 13
11 Coal, cost per car mile ..... 5.22 cent
12 Coal, cost per kw. h. including house service and all boiler feed 1.96
13 Coal, cost per lamp hour including house service 0.088
14 Round trips made by locals, 861—1st to 11th floor—142 feet.
Also 16—Basement to 11th—155.5 feet.
Total distance traveled in one direction, 124,750 feet.
15 Round trips made by express, 680—1st to 21st floor—268.5 feet.
Also 105—Basement to 21st—282 feet.
Total distance traveled in one direction, 212,190 feet.
16 Number of feet traveled in one direction or ½ total travel for day of 9 hours 336,940
17 Total number of feet per hour traveled in both directions 74,874
18 Average number of car miles per hour 14.18
19 Elevator fuel per hour, 489 lbs costing $0.71
20 Electric and house pump fuel per hour, 644 lbs $0.97
21 Mechanical efficiency of pump ..... 89.6 per cent
22 Indicated pump horse power (mean of cards) 130.29
23 Water horse power delivered by pump 116.7
24 Steam used per mile car travel (approximate) 252.8
25 Saving in steam when compared with compound duplex pump .... 28 per cent
26 Coal used per mile, car travel 34.4
27 Saving in coal when compared with the compound duplex pump .. 35 per cent
28 Car miles for day of 9 hours 127.63
29 Pump used ..... Laidlaw, Dunn Gordon Flywheel, 17¾x22x22x12¼x30
30 Revolutions in 9 hours 13,896
31 Revolutions per minute 25.7
32 Slip total, per cent 3.87
33 Cost of coal per passenger lifted ..... 0.13 cent
34 Number of passengers in 9 hours (5040); round number 5000
35 Water horse power per car mile 8.23
36 Actual water pumped, gallons 612,758
37 Average water pressure during day in pounds per sq. in. 177
38 Water delivered per revolution, **gallons (actual)** **44.09**

Elevator Dimensions and other Data

Diameter of all plungers, 6½ in.

Thickness of shell of plunger freight and long run elevator ⅜ in.

Thickness of shell of plunger short run elevator, $\frac{5}{16}$ in.

Plunger weights, total of plunger with central rope, long run passenger elevators, 8460 pounds. Total of plunger with central rope, short run passenger elevator, 4000 pounds.

Counterweights: Freight elevator, 8000 lbs.
Long run elevator, 7900 lbs.
Short run elevator 4700 lbs.

Ropes: Counterweight ropes per foot, 7.2 lbs.
Counterweight, total weight, freight, 2150 lbs.
Counterweight, long run passenger, 2050 lbs.
Counterweight, short passenger, 1121 lbs.

Weights of car:

Frame and panels: freight elevator, 3500 lbs.
long run passenger, 2500 lbs.
short run passenger, 2300 lbs.

Cab Weight: each passenger cab, 1125 lbs.
Friction each machine, up, 500 lbs.
Friction each machine down, 300 lbs

Cubic contents of building, 3,990,000 cu ft.

Height, 298 feet above curb.

Lot area, 10,920 ft.

Total floorspace, 140,000 sq. ft.

DISCUSSION

MR. THOMAS E. BROWN Mr. Herschmann's paper is very valuable as it applies to a type of elevator which is the subject of much speculation, and has been accepted entirely on the statements of the various makers, and has never before been tested by disinterested engineers.

2 The boiler tests give results seemingly lower than might have been expected. The day's run of the compound pump resulted in 131.74 car miles at a cost of 7000 pounds of coal. The day's run of the flywheel pump resulted in 127.63 car miles at a cost of 4400 pounds of coal.

3 This raised in the proportion of the car mileage = 4540 pounds against the compound's 7000 pounds, or a saving in favor of the flywheel pump of 2460 pounds, or 1.1 long tons, which, at $3.40, amounts to $3.74 per day, or $1122 per year of 300 days.

4 When we consider that the cost of the flywheel engine is usually more than double the cost of the compound duplex pump, it is a question whether with so small an annual saving the extra cost of the higher class apparatus is warranted.

5 The automatic valve mentioned in paragraph five, as saving 5 per cent, and which is shown and marked "check valve" in Fig. 6 is a device commonly used with all types of non-circulating hydraulic elevators, and has its counterpart in the circulating type in the "relief valve" in the water chest.

6 This check valve has for its primary object, in all types of elevators, the prevention of a vacuum in the cylinder during up motion stops, should the operating valve be too rapidly closed, and any economy resulting from its use is purely accidental. Any water sucked through this valve during the process of making an up motion stop is a saving, but as the amount is dependent on the handling of the valve by the operator, to the load in the car, to the speed of the car, and to the number of up stops made, as well as how they are made by the particular attendant operating the elevator, conditions continually changing, it would be very interesting to know how Mr. Herschmann arrives at the flat rate of 5 per cent saving.

7 The writer has used this device for many years, but has never claimed for it any substantial or fixed percentage of saving.

Referring to Fig. 6, it will be evident that the back pressure used to operate the check valve is discharged into an open suction tank and is therefore lost. Had the auxiliary discharge tank been connected directly to the suction of the pump, producing a suction head, an

absolute saving proportional to the suction head could have been attained.

8 The writer is informed that the back pressure is 25 pounds, and if this is the case the saving, were it used as suction head, would be be 25 : 180 = 13.9 per cent.

9 The introduction of an automatic check valve, by-passing the operating valve and also the automatic terminal stop, as shown in Fig. 6, is dangerous, as, should this check give out, all the controlling devices are rendered inoperative, the hydraulic friction is greatly reduced, and the car will accelerate to a dangerous speed with nothing to stop it until it strikes the bottom. In the writer's opinion such a check should be connected outside of the limit stop, so that in the event of failure of the check valve, the limit stop would still be operative to stop, or at least retard, the car when it approached the bottom.

10 An accident occurred some ten years ago from the failure of such a check valve which would have been fatal to several persons had the check not been connected outside of the limit stop. It is preferable so to graduate the operating valve as to avoid the use of a check valve, and this has been done in several installations, but it involves careful design and graduation of the operating valve to meet the conditions of each particular case, and is, therefore, not considered commercial.

11 A comparison of the "high rise" plunger elevator machines in the Trinity Building, with high rise geared hydraulic elevator machines, is interesting. For such a comparison the writer has chosen the elevators of the Hanover Bank Building, Pine and Nassau Streets, New York City. Careful tests of these elevators were made in May, 1904, by Mr. J. R. Furman, Any type of pumping engine may be applied to any type of hydraulic elevator; hence, in making a comparison of elevator machines, we should compare the actual machines themselves, irrespective of the nature of the pumping plant, as, manifestly, with any given pump efficiency the final efficiency is entirely dependent on the efficiency of the elevator machine and, therefore, such a comparison should be made on the actual pressures used and actual displacements of the respective hydraulic cylinders when performing equivalent duties.

12 The Hanover Bank plant consists of six high rise and five low rise elevators, or eleven in all. In this comparison, high rise elevators only are considered. The six elevators have each a rise of 304 feet. The cylinders are 19 inches in diameter, and are geared 8:1. The pressure from an open reservoir, and constant, was 152 pounds per square inch.

13 From the tests the underbalance was found to be 810 pounds,

the frictional resistance to be 690 pounds, and the mechanical efficiency 87 per cent.

14 The load and speed performances were as follows:

Speed with 180 lbs. in car, 940 ft. per min. Stopping distance not taken.
Speed with 1000 lbs. in car, 815 ft. per min. Stopping distance, 15 ft.
Speed with 1500 lbs. in car, 750 ft. per min. Stopping distance, 10 ft.
Speed with 2000 lbs. in car, 645 ft. per min. Stopping distance, 8 ft.
Lost time, 4 seconds.
Speed with 2500 lbs. in car, 600 ft. per min. Stopping distance, 8 ft.
Lost time, 3½ seconds.
Speed with 2700 lbs. in car, 525 ft. per min. Stopping distance not taken.
Speed with 3000 lbs. in car, 425 ft. per min. Stopping distance, 7 ft.
Speed with 3200 lbs. in car, 400 ft. per min. Stopping distance not taken.
Speed with 3400 lbs. in car, 300 ft. per min. Stopping distance not taken.
Speed with 3600 lbs. in car, 225 ft. per min. Stopping distance not taken.

Up motion hydraulic friction loss deduced from above data in pounds per square inch $=0.425 \times$ (car speed in feet per second).^{2}

Running tests: round trip distance run 608 feet.
Load 600 pounds, 40 stops: 20 up, 20 down. Round trip, 3 minutes 22 seconds.
Load 600 pounds, 20 stops: 10 up, 10 down. Round trip, 2 minutes 26 seconds.
Load 1500 pounds, 40 stops: 20 up, 20 down. Round trip, 3 minutes 10 seconds.
Load 1600 pounds, 20 stops: 10 up, 10 down. Round trip, 2 minutes 30 seconds.
Load 1600 pounds, 20 stops: 10 up, 10 down. Round trip, 2 minutes 19 seconds.

15 On December 1, 1905, the writer timed the same elevators in ordinary service between 1:30 and 2 o'clock p. m., with the following results.

Nine round trips:

Fastest, 3 stops, 1 up, 2 down. Time round trip, 74 seconds.
Slowest, 10 stops, 4 up, 6 down. Time round trip, 106 seconds.
Average, 5⅓ stops; 3⅓ up, 2⅓ down. Time round trip, 95 seconds.

Average number of passengers, up trips, 6.
Average number of passengers, down trips, 4.

Thirteen stops were timed, varying from two seconds shortest to four seconds longest. Average stop, 2.8 seconds. This is the time the car was actually at rest, discharging and receiving passengers.

16 By comparing the fastest and slowest runs it will be seen that the total lost time per stop, including retardation and acceleration, was a trifle less than 4.6 seconds. Deducting 14 seconds for three stops of quickest run, we find the running time to be 60 seconds; distance traveled 68 feet, or an average speed of 608 feet per minute. Hence these cars are traveling in service at the limit of speed for express elevators allowed by the Bureau of Buildings' Regulations.

17 From the speed load tests it will be noted that the elevators can carry 2500 pounds at this speed.

Taking the longest trip when ten stops were made	= 106 seconds.
Adding 4.6 seconds × 2 or two extra stops	= 9.2 seconds.
Time of round trip with 12 stops	= 115.2 seconds.
Hence, Hanover—time of round trip of 608 feet	= 1 min., 55.2 seconds.
Trinity —time of round trip of 537 feet	= 2 min., 14 seconds.

18 The Hanover time includes loading and unloading passengers, while in the Trinity tests the doors were simply opened and closed and no passengers handled.

19 The overrunning distance, *i.e.*, length of stop of the Hanover elevator, when at a speed of 750 feet per minute, with only 1500 pounds in car and an underbalance of only 810 pounds, was but 10 feet, while at only 490 feet speed, with 1617 pounds in the car, and the large underbalance of 2135 pounds, the Trinity elevators required 12 feet 4 inches to stop in and lost 8½ seconds in getting back to the landing.

20 It is to be regretted that the lost time on this test at the Hanover Bank was not taken, but in the succeeding tests, with an eight feet overrun, the time lost was four seconds; hence, we can infer that in the previous case it was about five seconds.

21 From the tests given by Mr. Herschmann, it may be readily figured that the up motion hydraulic friction loss of the Trinity elevator is about, in pounds per square inch = 0.78 × (car speed in feet per second)^2, or nearly double that of the Hanover Bank elevators. The Hanover Bank machine lifted 3600 pounds at 225 feet speed.

22 Mr. Herschmann does not give the load lifted at that speed, but from the data given it figures a little over 3000 pounds.

The mechanical efficiency Hanover Bank	87 per cent.
The mechanical efficiency Trinity Building	91½ per cent.

23 The excessive overbalance of the Trinity elevator, viz: 2135 pounds, necessary to overcome the momentum of the heavy moving masses, as against 810 pounds of the Hanover Bank elevator, makes the ratio of live load to gross load lifted 61 per cent, and 82.6 per cent, respectively, bringing the final efficiency or ratio of live load lifted to work done on plunger and piston for:

The Trinity elevator to	56 per cent.
The Hanover elevator to	72 per cent.

24 The plunger displacement of the Trinity elevator per car mile traveled = 4550 gallons, which, at 180 pounds pressure = 7.85 water horse power hours per car mile.

25 The piston displacement of the Hanover elevator per car mile = 4870 gallons, which, at 152 pounds pressure = 7.1 water horse power hours per car mile.

26 If we reduced the pressure of the Hanover elevator to that necessary to do the duty of the Trinity elevator, viz.: 3025 pounds at 225 feet, it would be 136 pounds instead of 152 pounds per square inch, and the power per car mile = 6.4 water horse power hours per car mile, or only 81.5 per cent of the power required by the Trinity elevator to do the same duty.

27 The argument is made that the plunger elevator is absolutely safe, and that this offsets any difference there may be in economy and service with high rises at high speeds. Let us consider this question:

28 There are no safety devices whatever on the Trinity machines except a top and bottom limit stop. This limit stop is operated by a wire cable, and is (see Fig. 6) separated from the cylinder by several tees, elbows, long nipples, etc., and also is by-passed by a check valve.

29 The test of No. 3 elevator shows that it can descend at a speed of 885 feet per minute = 14.75 feet per second with a load of 1756 pounds in the car.

30 The weight producing descent is therefore 1756 + 2135 pounds, underbalance = a total of 3891 pounds. Deducting the descending friction as given by Mr. Herschmann, viz: 300 pounds, leaves for production of speed 3591 pounds, which produced a speed of 14.75 feet per second.

The load $3591 \div 33.2 = 108.1$ pounds per square inch in cylinder.
The back pressure is said to be = 25 pounds per square inch.
Whence pressure producing speed = 83.1 pounds = hydraulic loss at 14.75 pounds speed, or

Descending hydraulic loss in pounds per square inch	$= 0.39\ V^2$
Of this the loss in the operating valve and automatic stop would be about	$0.16\ V^{22}$
In pipes and bends about	$0.06\ V_2$
And in cylinder itself about	$0.17\ V$
Total	$0.39\ V^2$

31 Hence, with a load in the car of say 2500 pounds, the car could descend and strike bottom at a speed of 980 feet per minute should the operating valve and terminal stop valve fail simultaneously.

32 Should the automatic check valve fail to close, the hydraulic resistance of the operating and terminal stop valves would be entirely eliminated and the total hydraulic resistance reduced to about .23 V^2, and the car would strike at a speed of 1280 feet per minute.

33 Should the "to and from pipe" gi[illegible], the hydraulic resistance would be reduced to about 0.17 V^2, the back pressure of 25 pounds would be gone, and the car would strike the bottom at a speed of 1660 feet per minute. The result of such an occurrence requires no comment.

34 The writer is of the opinion that the plunger, or any other type of elevator, should be provided with automatic regulators, preventing excessive down speed, and in addition be provided with retarding devices, independent of the operating machine, which will stop the car under any condition of loading in a long enough distance to prevent injury to the passengers at the highest speed at which the car can reach the bottom. Sufficient pit room should always be provided at the bottom of an elevator shaft in order that this result may be accomplished. It is to be regretted that this is rarely done.

35 The diagrams and comparative table, herewith, will show these comparisons more conveniently.

	Trinity	Hanover
Type	Plunger	Geared hydraulic
Rise	282 feet	304 feet
Diameter of ram and cylinder	6½ inches	19 inches
Gear-ratio, car to piston travel	1:1	8:1
Pressure	180 pounds	152 pounds
Areas	33.2	278
Maximum lifting force $= \frac{\text{area} \times \text{pressure}}{\text{gear}} =$	5976	5300
Mechanical efficiency	91.5 per cent	87 per cent
Mechanical friction	500 pounds	690 pounds
Underbalance	2135 pounds	810 pounds
Effective lifting force at 0 speed	3341 pounds	3800 pounds
Lifting efficiency (live load)	56 per cent	72 per cent
Hydraulic loss in terms of car velocity in feet per second	0.78 V^2	0.425 V^2
Moving mass at car velocity =	22,035 pounds	9500 pounds
Underbalance required for equally short stops	2980 pounds	810 pounds
Overrun (stopping distance) with 1617 pounds at 490 feet	12 feet 4 inches	
Overrun (stopping distance) with 1500 pounds at 750 feet	10 feet	
Overrun equated to load and velocity	12 feet 4 inches	4.15 feet
Trinity, 537 feet travel. Hanover, 608 feet travel:		
Time of round trip, making 12 stops	2 m. 14 s.	1 m. 55.2 s.
Time of round trip reduced to 537 feet travel	2 m. 14 s.	1 m. 48 s.
Speed with 1500 pounds load (see curves)	522 feet	750 feet
Speed with 2500 pounds load (see curves)	350 feet	600 feet

Speed with 3000 pounds load (see curves)	232 feet	425 feet
Gallons displacement per car mile	4550	4870
Water horse power hours per car mile	7.85	7.1
Water horse power hours reduced to same load and speed	7.85	6.5
Ratio of power used for same useful work	1.000	0.825

MR. WILLIAM H. BRYAN I desire to make a record here of what appears to be the most efficient hydraulic elevator plant in operation. It consists of ten plunger machines in the May Co. department store, St. Louis. Their service is as follows:

a Three passenger cars, rated load 2500 pounds, maximum, 3000, travel 80 ft. 6 in.

b Three passenger cars, same loads, travel 68 ft. 6 in.

c One passenger car, same loads, travel 75 ft.

d Two freight cars, rated load 3000, maximum 3600, travel 85 ft. 6 in.

e One freight car, rated and maximum loads 2750, travel 14 ft. 6 in.

2 The plant was installed within the last year by the Standard Plunger Elevator Co., of New York. Previous to contracting for it the May Co. had entered into an agreement to purchase its entire power and lighting service from an outside central electric station. This necessitated that these elevators be driven by electric pumps. These pumps were included in the elevator contract, and consisted of three Allentown single acting triplex pumps with vertical plungers, 9″ diameter, 10″ stroke, each direct chain driven by a 50 horse power Bullock electric motor, designed for 480 volts direct current. Speed of pumps, 50 revolutions per minute; motors, 300. The installation was made under a very stiff guarantee as to efficiency, and the contractors were given a free rein as to the methods by which they could cut down current consumption. They therefore installed what they called a double pressure system, but in reality there are four different pressures in use, two working and two discharge, with two independent working pressure tanks and two independent discharge tanks. By means of regulating and check valves the ascending car automatically selects its water from either of the two working pressure tanks. The higher of which carries about 150 pounds pressure and the lower about 120. Light loads are served by the lower of these two pressures, and heavy loads by the higher. Descending, the car again selects the discharge tank into which it will deliver its water, the higher of the two tanks usually carrying about 45 pounds pressure and the lower about 15 pounds. Lightly loaded

cars discharge into the low, and heavily loaded into the high pressure discharge tank. It will be noticed that the net working pressure on the pumps for both empty and loaded cars making round trips is about 105 pounds.

3 This arrangement differs from previous multiple pressure systems which have come under my observation in that the heavily loaded descending car discharges its water against a high pressure, which pressure is available for reducing the work on the pumps. These latter automatically select high pressure water on their suction side, so long as it is available, and when it fails they take water from the low pressure tank.

4 A recent test was made with the passenger elevators making round trips every two minutes, the two freights every five minutes, and the short lift every two minutes, stopping at all floors, the cars carrying their full rated loads. For this service one pump was in continuous operation, and a second 25 per cent of the time, the third being idle, in reserve. The working pressures were changed slightly for this test, loading as follows: working; high 149, low 118.5; discharge; high 38.6, low 16. The efficiencies were found to be 4.05 kilowatt hours and 4.30 water horse power hours per car mile of travel, a result which, so far as I can learn, has never before been reached for heavily loaded cars.

5 The apparatus is the invention of Mr. Thure Larssen, Chief Engineer of the Standard Plunger Elevator Co.

MR. E. S. MATTHEWS This paper gives us a series of observations on the Trinity Building direct acting plunger elevators from which valuable conclusions may be deduced regarding the suitability of such elevators for high buildings.

2 We do not find any statement of the maximum net load raised at slow speed, but this is readily deduced from the data given.

3 However, an observation on this point is always valuable, for it gives the basis for determining the mechanical efficiency of the machine, and also a valuable point in plotting speed curves; furthermore, by a comparison of this load, which is quickly and easily made, with the total hydraulic lifting power of the water, a rough conclusion may be at once drawn as to the economy of the apparatus.

4 From Mr. Herschmann's data this elevator under 177 pounds pressure will raise 3218 pounds slowly, while the total lifting power of the water is 5873 pounds; or the elevator carries continually somewhat over a ton and a quarter of dead weight up and down the hatchway, giving a maximum live load efficiency of 55 per cent.

5 This must be considered a little disappointing as high rise high speed hydraulic elevators commonly show 70 per cent. This was the result of tests in the Stock Exchange Building, Woman's Temple, Teutonic Building, and others at Chicago, while in a test at the Masonic Temple and Great Northern Office Building, also at Chicago, the live load efficiency was much higher than 70 per cent.

6 The cost per car mile travel of 5.22 cents and 8.04 cents with compound duplex and high duty pumps, respectively, must also be considered wasteful when we compare the performance of the Teutonic Building and others of its class, where the elevators with compound duplex pumps were run at about four cents per car mile while two cents per car mile has been repeatedly guaranteed and surpassed by high speed hydraulic elevators with high duty pumps.

7 This matter of fuel economy might be gone into quite exhaustively, but all engineers agree that it is of minor importance unless it assumes abnormal variation from customary standards; and as far as these elevators are concerned, the subject may be dismissed with the simple statement, that the fuel cost of their operation is about 50 per cent more than that of other well designed hydraulic elevator plants, giving higher and faster service.

8 Mr. Herschmann has given us some notes and observations on what might be called running tests of these elevators, which is a valuable departure from the ordinary, and which form an interesting portion of his paper.

9 Under the heading "Tests of Trinity Building Elevators" he gives us the result of what he designates as a "flying test" with a load of 1617 pounds in the car. The object of a "flying test" is to determine the highest speed attainable in a given elevator and the conditions of upward stop under these circumstances. The load for a "flying test" should be as light as possible. At a "flying test" in the Masonic Temple at Chicago, the Equitable Building, Atlanta, Ga., and others, the load in the car consisted only of the writer and one other person.

10 In Prof. Alden's paper on the Plunger Elevator, presented at the Washington meeting of our Society in May, 1899, in discussing this subject, he takes the car with no load whatsoever at its maximum speed, and at the top of the hatchway.

11 To make a "flying test" with a car loaded with nearly a ton would seem to be inadvisable and such a test could be better designated as a "running test with a well loaded car."

12 However, the omission of this observation is not a serious

matter, as we can easily deduce the results of such a test from the data given us by Mr. Herschmann.

Let V = velocity of the elevator in feet per second.
Let R = the retardation or minus acceleration of the system under the given conditions.
Let B = Net retarding force in pounds.
Let D = Distance traversed in feet in coming to rest.
Let Q = Total pounds weight moved at car velocity.
Let l = live load in the car in pounds.
Let p = the total plunger weight in pounds.
Let f = pounds weight of frame and panels.
Let c = pounds weight of car.
Let r = total pounds weight of counterweight ropes.
Let b = pounds weight of counterweight ropes unbalanced so as to produce ascent (which may be + or − according to the location of car in hatchway).
Let w = pounds weight of fixed counterweight.
Let u = upward friction of elevator in pounds.
Let h = total upward back pressure on plunger in pounds.
Let g = acceleration of gravity in feet per second.

13 Let the elevator be in upward motion, and the hydraulic pressure causing such ascent to be cut off.

Then

$$D = \frac{V^2}{2R} \qquad [1]$$

and

$$R = \frac{B}{Q}\, g. \qquad [2]$$

$$B = p + f + c + l + u - w - b - h \qquad [3]$$

$$Q = p + f + c + l + r + w \qquad [4]$$

The value of R in a properly designed high speed hydraulic elevator is about 6 *when the car is lightly loaded.* A mental calculation shows that this will produce a natural stop when running at 600 feet per minute in $8\frac{1}{3}$ feet.

14 The values of R in the Trinity Building elevator are as follows:

When loaded with operator weighing 150 pounds,

$$R = 2.96 \qquad [5]$$

When loaded with 1617 pounds,

$$R = 4.77 \qquad [6]$$

At a speed of 600 feet per minute

$$D = \begin{cases} \text{with 150 pounds load} & 17 \text{ feet} \\ \text{with 1617 pounds load} & 10\tfrac{1}{2} \text{ feet} \end{cases} \quad [A]$$

At a speed of 490 feet per minute

$$D = \begin{cases} \text{with 150 pounds load} & 11 \text{ feet} \\ \text{with 1617 pounds load} & 7 \text{ feet} \end{cases} \quad [B]$$

15 These tabular results indicate the shortest possible stops of this apparatus made by a theoretically perfect controlling valve and they cannot possibly be made shorter; but actual practical stops exceed these by a considerable amount even with the best controlling valves. Mr. Herschmann's paper gives these actual stopping distances and we learn that with a load of 1617 pounds, at 490 feet per minute, the actual stopping distance was 12 feet 4 inches, instead of 7 feet, as shown by the above table, or that the controlling apparatus took about two times the distance in stopping that the shortest natural stop of this apparatus calls for.

16 Both the overrunning distance and time lost are about twice as great as would be permitted in good practice.

17 The results of the running tests, opening and closing doors, etc., are remarkable, and when the nature of the controlling apparatus, and the small valves of R are taken into account, they must be considered as highly creditable to the elevator operator.

18 On the first page of Mr. Herschmann's paper he alludes to an economy of 5 per cent through the action of an automatic valve operating on the up stops.

19 It would be interesting to know from what observations the result was deduced; for this valve can deliver no water to the elevator during normal operation, unless the stop is made as short as the laws of gravity and momentum will permit. In the observation just spoken of it took about two times as long to make the stop as these natural laws called for, and briefly there does not seem to be a single observation in Mr. Herschmann's paper where this valve could have possibly delivered even a drop of water into the system.

20 The writer would have been glad to have the opportunity of analyzing a series of observations supporting any such claim, and would suggest that a computation of probable error of the result would undoubtedly have found such error to exceed 5 per cent.

21 Only the high rise elevators are equipped with this back pressure check valve device, the low rise elevators being provided with an entirely different apparatus; both of these devices are intended to

prevent the plunger from leaving the water in case of defective operation of controlling valves, and the back pressure device accomplishes quite another important additional function, which is undoubtedly the reason for its use.

22 The check valve designated by Mr. Herschmann as the automatic valve is merely an incident in the case. This check valve is an old device and no claim for economy has ever been made for it.

23 The back pressure check valve device is simply the employment of a water counter-balance; and that is evidently the reason why it was used on the high rise elevators only.

24 The short rise elevators having less mass in motion are easier of control, and we have seen that in the high rise elevators, even with the employment of water counter-balance, the values of R become much less than is sanctioned by good practice.

25 As the value of R decreases, the elevator approaches the absolutely uncontrollable state and it may be interesting to see how the use of the water counter-balance increases the value of R and, therefore, renders the elevator more controllable.

26 Referring to equation [2] we see that

$$R = \frac{B}{Q}\, g, \qquad [2]$$

or substituting the values in [3] and [4] for B and Q, we have

$$R = \frac{p+f+c+l+u-w-b-h}{p+f+c+l+r+w}\, g. \qquad [7]$$

27 If we now diminish the value of w and add the same amount to the value of h, the value of the numerator of this fraction is unchanged but the value of the denominator is decreased; hence R is increased and the elevator is rendered more controllable.

28 The subject of elevator control is worthy of serious consideration for it has more to do with the safety of passengers and the rendering of efficient service than any other problem connected with an elevator installation.

29 The writer submits herewith in Fig. 1 a sectional elevation of the pilot controlling and terminal automatic stop valve in actual use in the Trinity Building.

30 The drawing submitted by the writer will be found to agree with the plan and elevation of Fig. 1 and Fig. 2 of Mr. Herschmann's paper.

31 This mechanism will be seen to be of considerable complexity

but it is interesting to note how the substitution of a hollow-plunger for the telescoping cylinders, shown at the upper right hand of the

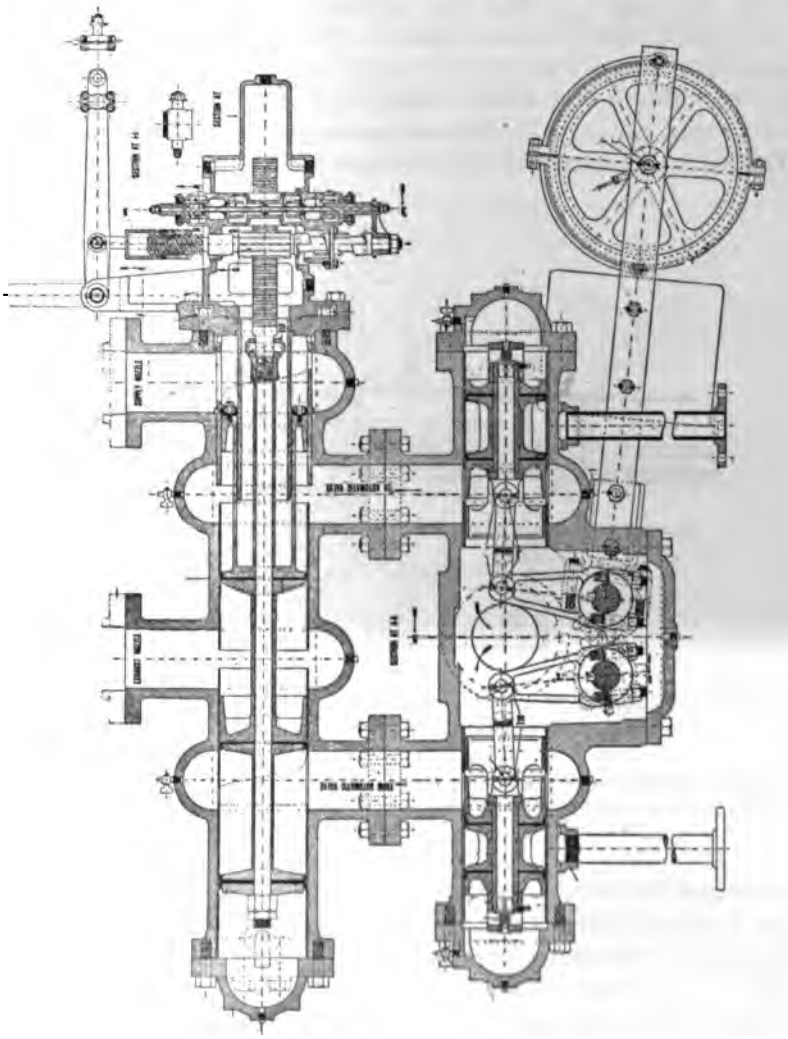


FIG. 1 PILOT CONTROLLING VALVE AND TERMINAL SAFETY STOP VALVE IN ACTUAL USE AT THE TRINITY BUILDING

valve structure, would have simplified the apparatus, diminishing its necessary diameter, length, and number of parts avoiding the

special –U packings and obviating heavy dragging weight upon the valve lining. The modification of this valve is shown in diagram as Fig. 2.

32 The motion between main and pilot valves in the Trinity Building is accomplished by a rack, pinion, screw, suspended nut, and connecting bracket. The simplification of this motion and the avoidance of lost motion is shown by an inspection of Fig. 3 which represents the connecting motion of the Moore Patent, consisting of a single lever. This patent was once owned by the Crane Elevator Co., but expired long

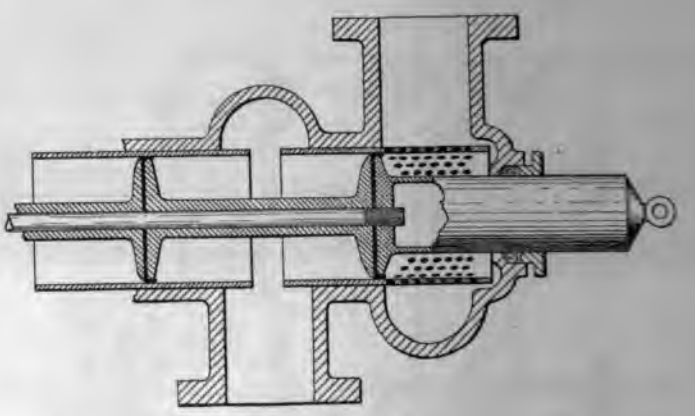


FIG. 2 SIMPLIFICATION OF SUPPLY PART AND ACTUATION AREA OF CONTROLLING VALVE SHOWN FIG. 1

NOTE—This construction was in use and published about half a century ago; and illustrates the fact that some modern devices are not improvements on "the work of the ancients."

since and has been for years public property. The suspended nut on the Trinity Building valve motion is prevented from revolution only by the directive tendency of two links whose resistance to torsion is governed by short bearings; and an inspection of the actual working construction at the Trinity Building now shows a lost motion at this point of something like a quarter of an inch. These are the mechanisms by which the operator controls the operation of the car and a motion of the pilot valve of about an inch is all that is required to differentiate between full speed and absolute stop. It should be comparable in positiveness and simplicity to a locomotive throttle, but the valve motion of the Trinity Building is really so wide a

departure from the previous practice of engineers as to call for more than a passing notice.

33 The terminal automatic stop valve here shown is operated by two traveling wire cables extending four times up and down the

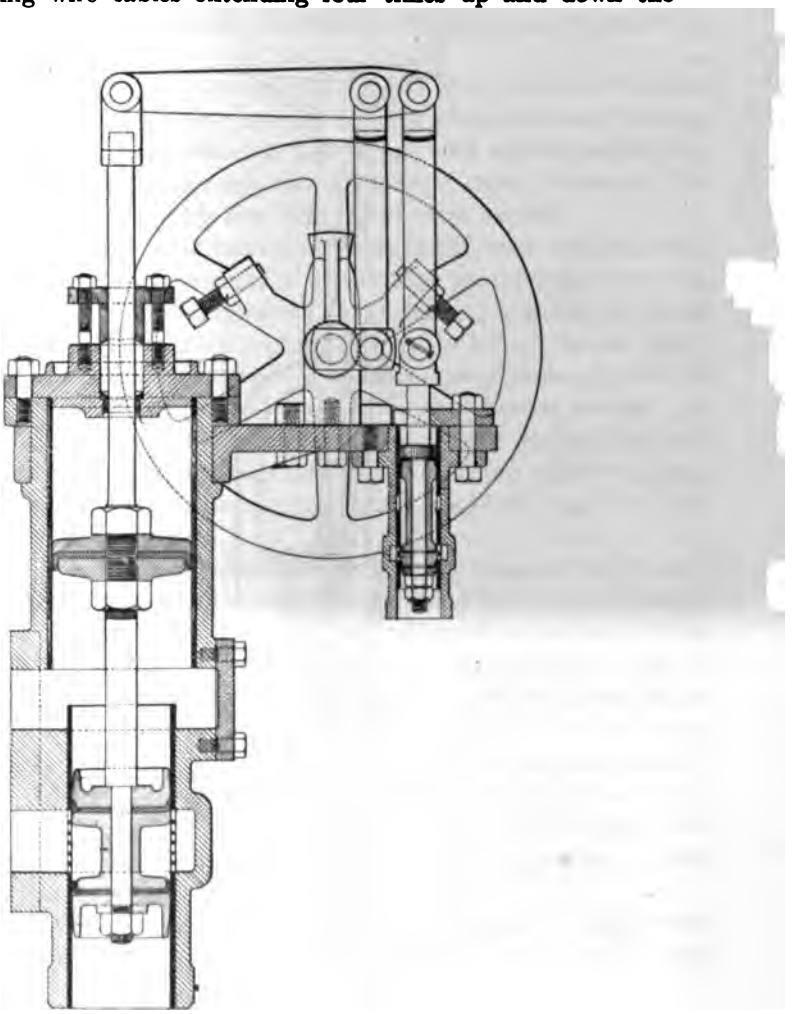


FIG. 3 THE SIMPLE AND EFFECTIVE VALVE MOTIONS OF THE EXPIRED MOORE PATENT

hatchway, each about 600 feet long. The approved previous practice has been to cause the action of such safety stop in some absolutely positive manner by rigid transmission of iron to iron, and Fig 4.

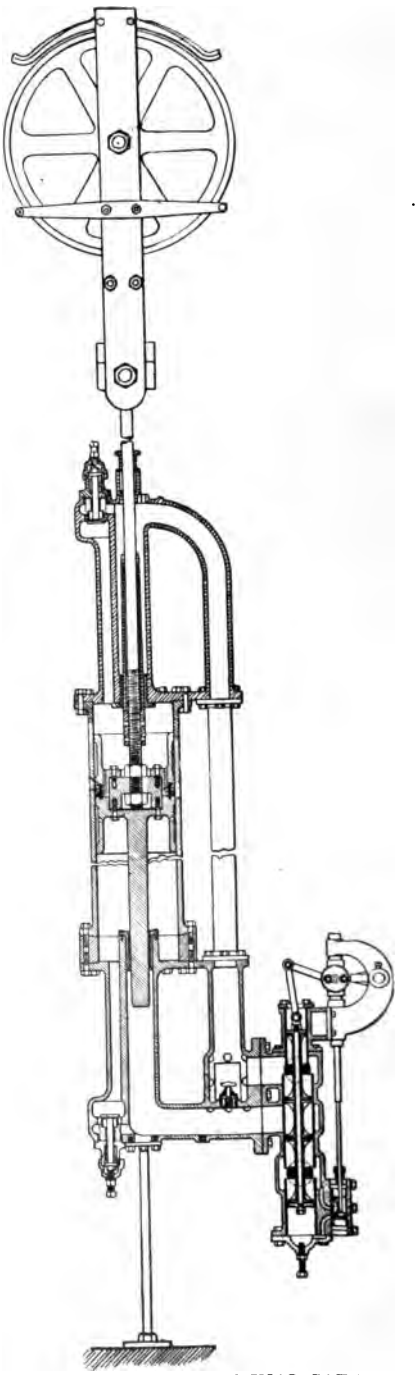


FIG. 4 THE SIMPLE AND POSITIVE TERMINAL SAFETY STOP DEVICE OF BASSETT

shows the device of Bassett consisting of cones positively carried by the motion of the piston itself.

34 It is to be questioned whether the actuation of a terminal safety stop by long cables subject to stretch, wear, and kinking, or jumping from wheels, as well as possible breakage, is a departure in the right direction.

35 It being generally conceded by those who know that in case of failure of piping valves or connections, the plunger elevator having no safety device will descend at high speed with serious results, the question arises as to the respective chances of piping failure in the plunger elevator and cable breakage in the cable elevator.

36 The cables of an elevator are always readily seen and inspected whereas the piping connections of an elevator are often subjected to severe and hidden initial stress due to the drawing together of joints in "making up." Elevator piping failures are by no means infrequent; water mains often break, and when the plunger elevator is stopped and the momentum of its mass (about eleven tons in the Trinity Building) is checked, elevator piping and connections are strained in a much more serious manner than are the cables or piping of a cable hydraulic elevator. The writer considers that the two risks are about equivalent.

37 Let us examine the conditions existing as regards plunger and casing when the car is at the lower landing and full lifting power is exerted by the machine, as this is the landing where the car is fully loaded. The maximum pressure given in Mr. Herschmann's paper is 190 pounds per square inch, and when this pressure is applied to the lower end of the plunger it is augmented by the pressure due to a submergence of the plunger of 282 feet or 122 pounds per square inch, making a total lifting power of 10,352 pounds upwardly exerted upon the bottom of the plunger. This will not only raise the plunger itself (8460 pounds) but will cause the plunger to carry as a column a load of 1893 pounds.

38 As this plunger is fixed in direction at the top by a long brass sleeve the formula applicable to ascertain the conditions is that of Euler, viz:

$$P = 2\pi^2 \frac{EI}{L^2} \qquad [8]$$

When P = ultimate load, I = moment of inertia, L = length, and E is the modulus of elasticity.

39 For the Trinity Building elevators, E is 30,000,000, L is 3384 and I is 35.

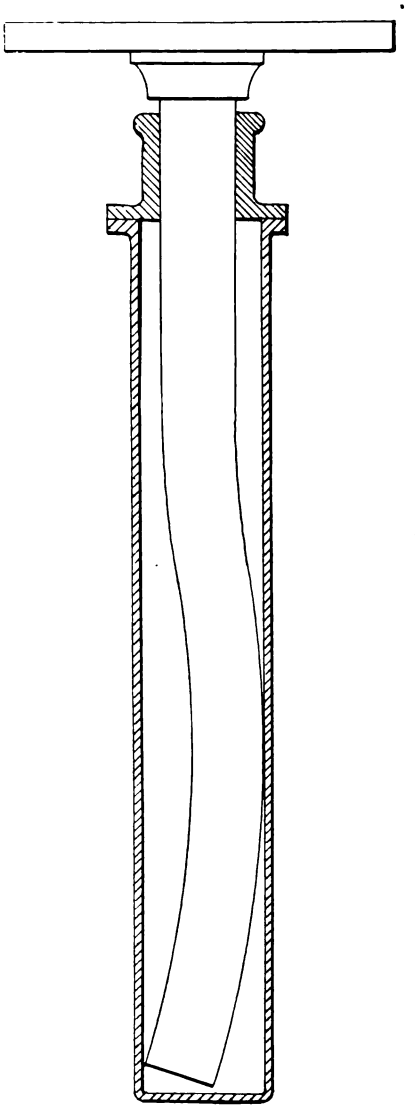


FIG. 5 (NO SCALE) DIAGRAM ILLUSTRATING THE BUCKLING OF LONG AND SLENDER PLUNGERS WHEN LOADED AT THE LOWER LANDING

40 A brief computation shows that the plunger would not hold itself up unless confined by its casing. What actually happens is this: The plunger bends against the casing, its lower end and upper convexities of buckling arcs dragging and grinding against it. This is illustrated by Fig. 5. The upper point of grinding on the plunger itself, theoretically, would occur at a distance of $\frac{L}{2\sqrt{2}}$ from the lower end of the plunger, but the variation in thickness of the tubing is sufficient to prevent any exact determination at this point; and in fact more than one point of flexure may occur and in some cases the corkscrew form is assumed by the plunger. I am informed that it has been found necessary to renew numerous plunger bottom sections in practice in various buildings. But a most serious question is in regard to the casing. It would seem to be costly if not altogether impossible to renew casings as deep as those of the Trinity Building; and if about two or three years' wear causes renewal of plunger bottoms, the wear upon the casing must be very appreciable.

41 Regarding the test of the multiple pressure system of hydraulic plunger elevators at the May Co. department store St. Louis, Mo. submitted by Mr. Bryan, I would say that the economy stated cannot be verified by an analysis of observations on account of the insufficiency of the data given.

42 The result is by no means remarkable for the pressures "were changed slightly for this test loading," thus employing the pressure in discharge tanks (or really the water counterbalance) in such a way as to secure maximum economy under the conditions of "this test loading."

43 Or exactly the same results of economy are obtained as in the case of specially adjusted counterbalance weights which might be arranged with reference "to this test loading."

44 Regarding the comment "a result which, so far as I can learn, has never before been reached for heavily loaded cars," I would call attention to the gravity lifting type of geared plunger elevators such as is installed in the American Tract Society Building and others where maximum economy is obtained with a full loaded car (where the energy consumed in its operation is merely the expenditure of work sufficient to overcome friction).

45 The multiple pressure system of operating hydraulic elevators is not new; the only question regarding it is a practical one, viz: Is the gain in economy worth the necessary expense of the complications involved in such a system? The experience of engineers thus far has answered this question in the negative.

46 In the course of development in every special line of the mechanic arts the lines of advance may be said to assume an angle dictated by good engineering practice in that particular line.

47 But occasionally abrupt divergences from such an angle occur, occasioned on the one hand in a normal manner by the advent of a meritorious basic invention, or on the other hand by a sporadic departure due usually to commercial exigencies merely. An example of the former is perhaps the steam turbine, and examples of the latter class are not wanting.

48 The writer has not given an exhaustive analysis of the elevators under discussion; to do so would be to write a book on the subject. He has called attention to a few considerations deemed to be important in a suggestive manner only, leaving the interested engineer to decide for himself in which class elevators such as these under discussion belong.

49 It is well to determine the result of some problems experimentally; and that of the comparative utility of plunger elevators for high rises is being rapidly advanced toward solution by that method.

MR. FREDERICK MERIAM WHEELER As particular emphasis is given in Mr. Herschmann's paper to the relative economies of the two types of elevator pumps used, it would have been well to have had each set of pumps properly designated and perhaps a brief description given. They are simply referred to, respectively, as a "duplex compound pump" and "a high duty fly-wheeel pump"—very incomplete and misleading names.

2 If I remember correctly, the former was a pump of the direct-acting type (running at the slow speed of 12 double strokes per minute on each side) and the latter a pump of the cross compound triplex type (averaging 25.7 revolutions per minute) having one high-pressure steam cylinder, two low-pressure steam cylinders, and three water cylinders.

3 Not only had the triplex pump the advantage of more economical steam distribution but its greater speed added much to its economy.

4 The paper would also have been more complete if indicator cards from the water cylinders of each pump had been given. It certainly would have been an interesting study to compare the cards from the two water cylinders (each of which were double acting) of the direct acting compound duplex pump with the cards from the three water cylinders (each of which were single acting) of the crank and fly wheel cross compound triplex pump.

MR. R. P. BOLTON There are several points in Mr. Herschmann's paper to which amendment should be applied.

2 No statement is made as to the number of short run elevators. I believe there are five, operated as way-cars to the eleventh floor.

3 Inasmuch as the main object of the test was the establishment of the economy of the elevator operation, an explanation would be desirable as to why the larger boiler was selected for the smaller load. (pp. 642–643) The tests recorded, bearing on other parts of the plant, do not appear to have any relation to the subject matter of the paper, and are not referred to, nor are any of the conditions explained in the text.

4 I suggest they should be transferred to the end, or to p. 643, as they prevent direct comparison between the two comparative tests with which the paper is concerned and which would be more conveniently arranged together.

5 (pp. 642–643) Items in tests, No. 17 should follow No. 13; No. 18 has no bearing on boiler results.

6 (p. 645) The results hereon are confusing in their present form, and are not placed in the order of the loads carried.

7 Explanation is needed of the load carried in test of locals 8, 9, and 10, which appears to be composed of four men, in addition to 653.5 pounds of dead weight.

8 (pp. 646–647) Items 8 and 25 are duplicates; items 12, 13, and 20 need explanation; 12 and 13 on p. 646 do not appear to include boiler-feed. The same items on p. 647, No. 12 does include boiler-feed, but No. 13 does not. How is No. 20 ascertained? Item 32: Why should a round number be given?

9 The last item (p. 648), I believe, should read: "Total net rentable area on 22 floors."

10 As to the subject matter of the paper, that is, the trials giving the ascertained results of coal consumption, car travel and passenger load, I have to say: I cannot agree with the author that such a form of trial has the value which would be afforded by a definite test with an ascertained load in the traveling machine, nor, with the estimated elements introduced, that it can be reliably depended upon to decide or compare with results in other buildings. Item 5: I cannot see how this statement of saving is borne out, as by comparison of items 16 and 36 (p. 647), we find that there was actually pumped 81,920 cubic feet while the ram travel recorded required only 77,496 cubic feet, leaving a discrepancy (or waste of water through valves or by leakage) of 4424 cubic feet. If, however, the over-run draws in 5 per cent more than the amount actually required, the ram travel

contents would be 77,496, less 5 per cent or 75,622 net, leaving to be charged to valve operation or leakage as much as 8298 cubic feet, or over 10 per cent of the total amount pumped.

11 The results reported in this paper aim to establish a direct comparison between the two types of pumps, to the advantage of the high duty fly-wheel pattern, by 35 per cent less fuel per car mile of elevator travel; But this does not seem to take into account the fact that the average load lifted was different in the two cases, and still leaves unexplained the unusual results reported with the direct acting duplex compound pump.

12 The load directly affects the traveling speed and, therefore, the mileage attainable within a given time is dependent upon it, and the method of comparison by car mileage is entirely misleading, unless the load which is carried be ascertained and stated.

13 The averages on these tests, at 140 pounds per person, including operator, are, for duplex trial, 511 pounds, and for the fly-wheel trial, 564 pounds in addition of 10 per cent to the load lifted by the duplex pump.

14 In the comprehensive test, which I conducted at the R. H. Macy Company's plant (Transactions 24, No. 0977, 1903), the cars carried a fixed load of 1000 pounds, with which the mileage recorded was attained.

15 The dynamic work, therefore, included in these two trials is but from 51 to 57 per cent of the Macy test, and the best stated consumption of coal is somewhat greater. The same (fly-wheel) type of pump, and of water tube boiler was used in the Macy test, the elevators being of standard hydraulic pattern with gear of 6 to 1.

16 The results when compared with the statements of this paper are as follows:

	Trinity Bldg.	Macy Bldg.
Fuel per car-mile	34.4	32.32
Steam per car-mile	252.8	231.5
Live load per car-mile	1,107,700 ft. lbs.	2,640,000 ft. lbs.
Live load per pound of fuel	32,137 ft. lbs.	81,370 ft. lbs.
Efficiency of work, related to thermal value of fuel	.034 per cent.	.080 per cent.

17 It will thus appear to be clear that the attempt to operate the plunger system at high speeds is accompanied by a considerable loss of efficiency. That this is to be expected is shown by the results of a comparison of an ordinary hydraulic passenger cylinder proportions with those of the express plungers described in the paper.

18 A speed of 518 feet with 840 pounds live load requires with a plunger, 6½ inches diameter, a pressure of 185 pounds per square inch. A speed of 600 feet, with 840 pounds live load, requires with a 16 inch cylinder and gear of 6 to 1, a pressure of 150 pounds per square inch.

19 Mr. Matthews has dealt with the really vital question in connection with the express elevators, described in the paper which is that of the extensive distance required for a stop in the up-run, and the necessary addition to the unbalanced load which is required to reduce that distance, at the same time affecting adversely the economy of operation.

20 The main difficulty with this type of machine is that at high speeds the unbalanced load must necessarily be increased to provide for a stop of the car within a safe distance, which standard practice has limited to a space of about eight feet.

21 The five express machines described in the paper are arranged with working parts of the weights, given on p. 423, so as to have an unbalanced weight of 2001 pounds. At a speed of 600 feet per minute, which, with a light load can be readily expected (under a pressure of 185 pounds and with about 600 pounds load) the gravity stop will require a space of 18½ feet.

22 To bring about a gravity stop within a distance of 12 feet, which is about the average space between office building floors, the unbalanced load should amount to 2241 pounds.

23 To bring about a gravity stop in the recognized safe space of 8¼ feet, the unbalanced load would be increased to 4611 pounds. This would then involve a working pressure at the pump of 220 pounds per square inch.

24 The loss of efficiency being larger in the high run, which are the express machines, it would have been of interest to learn the comparative water and fuel consumption of the two sections of the elevator apparatus. The express plunger machines are therefore being operated at their present economy at the expense of a safe stopping control on the up-run with light loads. Plungers of this length are subject to peculiar conditions as regards the nature of the support of the plunger itself.

25 Thus, in the long run of 283 feet, the plunger is in part hanging from the car, and only the following portions stand supported on the water in the cylinder:

At top of run with car empty,	69 feet standing,	214 feet hanging
At top of run with car full,	176 feet standing,	107 feet hanging
At half of run with car full,	138 feet standing,	3 feet hanging

to which peculiar combination is due the swaying of the neutral point in the plunger.

26 Such conditions are favorably modified, and other unfavorable features may be eliminated, when the plunger is of moderate length, and of larger diameter.

27 In conclusion, I desire to be distinctly understood as appreciating the general merits of the plunger type under those conditions of proper proportion of ram diameter to length and speed, and I have demonstrated that appreciation by having been the first engineer to adopt the plunger machine in New York City.

28 Finally, as a general proposition, I desire to impress upon you that the method of comparison of elevator operation by mere statement of car travel is all wrong. It is a case of the ingenious working of the devil around a stump. A car-mile run by an empty train is not to be compared to a car-mile run by a fully loaded train, and as the speed of all elevators varies according to their load, a heavily laden machine does not make the car-mile distance that a lightly loaded car will; and we should in any further tests have weights ascertained and stated.

29 I trust this discussion will have one important result, namely, to draw the attention of those responsible to the desirability of proportioning the plunger size to speed and travel. If that is attained, this paper, though in my judgment of no value as a record of operating conditions, will have accomplished a result of much general advantage.

MR. W. Y. LEWIS The title of this paper should have included some reference to the pumps so remarkably compared in the results given and perhaps the paper should have been entitled "The Influence of the Power Plant Design upon Elevator Operating Costs." Comparing the results with the data given in Mr. Pratt's paper on the Park Row Elevator Tests, one might conclude that electric elevators are far superior to the hydraulic plunger type, but this I believe is contrary to general opinion and actual fact. It shows, however, that the author's assumption, "That the plan adopted for the test would readily enable serviceable comparisons to be made with other tests," was quite unwarranted. I think the Society should draw up some regulations on a definite plan for the conduct of future elevator tests.

2 The point I wish to bring into view is that notwithstanding the great speed and large number of elevators, the time interval between both local and express cars is about 39 seconds so that the average time a person has to wait for a car is 20 seconds. If this time is taken into account, the average time of a journey to any floor is consider-

ably less than what one might imagine when such high elevator speeds are talked so much about.

3 In a continuous elevator the car intervals could be reduced to four or five seconds and it would give 40 per cent more capacity than the elevator described, in only 25 per cent of the space, so that the saving in rentable area would be enormous. I am very much surprised that up to the present nothing has been done in this country with continuous elevators, and would call the attention of architects and elevator engineers to the subject, as there are great advantages over the present intermittent service elevator systems lying dormant in the continuous elevator proposition.

No. 1129

A MECHANICAL ENGINEERING INDEX

By W. W. BIRD and A. L. SMITH, WORCESTER, MASS.
Members of the Society

1 Any one who has watched the industrial development of the last ten years has been impressed with the extended differentiation which has taken place. This perfecting of minor details of construction and the improvement of engineering methods has been attended with a corresponding growth in both descriptive and theoretical literature on the various subjects. One of the chief indications of this great increase in multiplicity of details, as well as of the fact that man's brain has reached its limit for retaining these details, is found in the popularity of the index idea. The recording and filing of the facts pertaining to a business or profession so that they may be instantly available; in other words, the construction of an infallible mechanical memory, has become one of the modern problems. To tell how one phase of this problem is being solved, namely, the building of a comprehensive Mechanical Engineering Index with a minimum expenditure of time, is the purpose of this paper.

2 The primary object of this index is to furnish references which will enable students and instructors in the Department of Mechanical Engineering at the Worcester Polytechnic Institute, to keep in touch with the latest and best literature pertaining to their special fields. It is intended that this index shall be comprehensive, but select rather than exhaustive. To accomplish the latter, its material is furnished by the instructors instead of by students. No material goes on file which has not been reviewed by some one competent to judge of its value. The field covered comprises: Articles from Periodicals; Papers from Proceedings and Transactions of Societies; Theses; Book Reviews; Manufacturers' Catalogues and Trade Lists. All of the leading engineering papers, foreign and domestic, about thirty in all, are regularly reviewed. These are apportioned among the ten or more readers of the Department, so as to equalize the work and enable each man to have, so far as possible, the literature pertaining to his spec-

Presented at the New York Meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

ialty. The work is done at the reader's own convenience, and to secure uniformity and economy of time, a record is made on the special card shown in Fig. 8, those specifications necessary to describe the article being underlined. Inasmuch as the title of the article does not always indicate the matter for which it is recorded, the reader prints on the upper edge of the card the title and sub-titles which will determine its place in the index. Each reader is supplied with a list of the index titles which are printed herewith. The object of recording illustrations is to afford a clue to cuts suitable for lantern slides. An amber colored card is used for these references, as white cards are too easily soiled. These cards properly filled out are brought into the weekly Department meeting, and the articles having special interest are discussed in an informal manner.

3 The selection of index titles and their grouping will always create a difference of opinion. As has been stated, the reader determines under what title the article shall be filed. To illustrate: If an article on Pumps is of value chiefly as a general review of the subject, then it would be entered directly under the main title Pumps. If it were a general discussion of Power Pumps, it would find its place under Pumps—Power. If the chief value of the article was found in a record of tests, then it would be put under Pumps—Tests, even though the tests were of a single type only, such as Power Pumps.

4 Some titles signify a single subject, as for instance, Lathes, while others signify several, as for instance Meters. Shall an article on Current Meters be filed under Meters—Current or shall it be filed under Hydraulics—Current Meter? In the same way, shall an article on Power Plant Chimneys be filed under Chimneys or under Power Plants—Chimneys? No rule can be formulated to cover all cases but in general it seems desirable to file under that title with which a subject is most closely affiliated. A general article on Chimneys would be filed under Chimneys, while one on the design of Power Plants as a whole but with some space devoted to Chimneys, would be filed under Power Plants—Design. An article on Crane Brakes would be filed under Cranes—Brakes. In the same way, it might be suggested that Steam Engines should be filed under Power Plants—Steam Engines, but in this case the subject of Steam Engines is of enough importance to make it a main title. And this might apply under certain conditions to any sub-title subject. Convenience for the user of the index rather than adherence to rigid classification should determine the question of grouping.

5 The problems involved in a catalogue file and index are somewhat different from those of a general reference index. Catalogues

should be filed so they can be quickly located, easily removed, and replaced without disarranging adjoining ones. As to the first, the great majority of catalogues have no back to which a label can be affixed. If the label is on the cover, and the catalogues placed on shelves like books, several may be pulled out before the right one is found. A tab made of gummed tape bearing the name or number of the catalogue and attached so as to project from its back will remove this objection. If the shelves have frequent partitions, the catalogues will stand up fairly well, but inasmuch as the catalogues are of different widths, some get pushed back and the others are easily disarranged. This last difficulty may be partially avoided if the catalogues are sorted into three common sizes and separate shelves assigned to each. A second difficulty presents itself when we attempt to index a catalogue covering a diversified line of manufactures. A steam engine catalogue takes care of itself, but one devoted to all kinds of machine tools, for instance, puzzles the indexer. To use a number of copies of the same catalogue filing one under each title is not satisfactory. Neither can the entire contents be indexed. Some system of numbering must also be provided which will permit proper grouping, expansion or contraction, and easy collating.

6 Several years ago the "American Machinist" advocated the following standard sizes for catalogues: 3½ x 6, 6 x 9, 9 x 12. Most manufacturers follow these standards but many do not. In the catalogue file now described three sizes of drawers are provided to accommodate catalogues of these dimensions. A catalogue is filed in a drawer nearest its size. If the catalogue is a little too large, it is trimmed accordingly. This may sometimes slightly mutilate the catalogue, but seldom enough to impair its usefulness. From five to ten per cent of the catalogues that are filed may require trimming. Catalogues are placed in the drawer with their backs uppermost. A gummed label with suitable specifications, like that shown in Fig. 12, is put on that part which will be the upper right hand corner as the catalogue lies in the drawer. Selection, removal and replacing is thus rendered as convenient as with a set of index cards.

7 Various ways of designating and arranging catalogues have been used. One method is to number and file in the order of accession without reference to contents. This provides easily for expansion and collating and conduces to compactness. If, however, a user wishes to consult all the principal catalogues of Water Wheels, for instance, he will spend considerable time in selecting and replacing them as they will be scattered through the entire collection. Another method is to arrange alphabetically by manufacturers' names. For those who

are thoroughly familiar with [illegible] talogues devoted to the different lines of manufactures, this ma[illegible] good arrangement, though it has the same defect as the previous [illegible]ystem. Yet another way is to arrange alphabetically according to principal contents. A modification of this last is the one adopted.

8 A set of titles has been selected which covers those individual products or groups of products in [illegible]which the Mechanical Engineer is directly interested. Blocks of co[illegible]ecutive numbers are assigned to each title, the range of numbers l[illegible]g in excess of the probable number of catalogues under that title. Th[illegible]e blocks consist of 10, 25, 50, or

FIG. 1 TAB CARD (Canary) FIG. 2 BOOKS—SUBJECT INDEX (Blue)
FIG. 3 BOOK REVIEWS—SUBJECT INDEX (Manila)

100 numbers. Inasmuch as additions to the original list of titles may be necessary it was not thought adv isable to attempt an alphabetical arrangement of the groups. The si es are designated by letters, A for the smallest, B for the medium, C for the largest, the catalogues for a given title being assigned the same block of numbers for each size and numbered in the order of accession.

9 In a special drawer is a card index or Directory of Manufacturers giving the name, letter size and number of their catalogue, thus facilitating quick selection when only the manufacturers' name is known. Under main titles in the general reference index is placed a special salmon colored card giving the range of numbers and a list of

all the catalogues of that set with the individual number and letter size. Inspection of this card or the one filed under the manufacturer's name will show if a catalogue is missing from the file.

10 In general the index consists of a series of tab cards on which are printed the names of the various subjects which are connected with Mechanical Engineering. All of these cards are arranged in alphabetical order and are easily found. To make out a consistent list of these subjects has been the chief difficulty of the work of preparing this index but the problem has been satisfactorily solved by having each subject connect in some way with one of the main or subdivisions of Mechanical Engineering.

FIG. 4 CATALOGUES (Salmon) FIG. 5 TRANSACTIONS (White)
FIG. 6 THESES—STUDENTS (Green)

11 The question naturally arises, What is Mechanical Engineering? and an answer can be found by turning to the tab card Mechanical Engineering. On this card we find:

See also Construction
Machine Design
Materials of Construction
Power
Transportation

Turning to the Power tab card, we find,

See Power Consumption
Power Cost
Power Measurements
Power Plants
Power Transmission

and following out one of these divisions, as, for example, Power Transmission, we find a whole line of topics which are still further subdivided.

12 The tab card may be simply a directory card with the directions for finding the required information, as for example, under Annealing we find, See Heat Treatment, which means that we must turn to Heat Treatment to find out about Annealing.

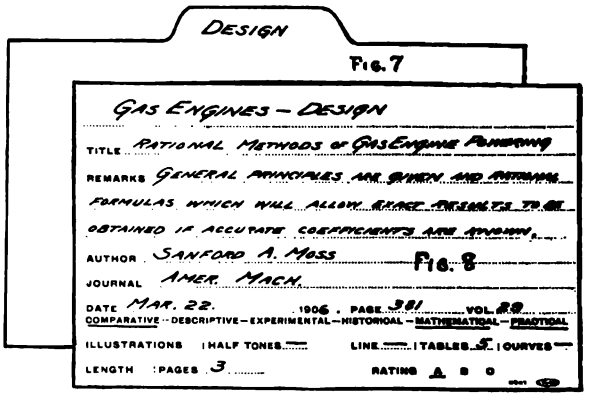


FIG. 7 TAB CARD (Canary)
FIG. 8 PERIODICALS (Amber)

13 If, however, the tab card says "See also" then the references are simply suggestive, while back of the tab card itself are the regular index cards. These are of various colors and have the following significance: Blue cards, Books; Salmon cards, Catalogues; Green cards, Theses; White cards, Transactions and Proceedings; Amber cards, Periodicals; and Red cards, Lantern Slides. To illustrate, we turn to Gas Engines, Fig. 1 is the tab card. Back of it we find a blue card, Fig. 2, the numbers at the right refer to envelopes, Fig. 3, which contain the written review and any other information which we may have with regard to the books. The next is a Salmon Card, Fig. 4, with a list of Gas Engine makers. The numbers refer to the catalogues. The 9 x 12 on the card being put there to call attention to the fact that these are the large size catalogues, the letter C being for the same purpose. The next salmon card without the C or 9 x 12

has a list of 6 x 9 catalogues and as this is the prevailing size, no letter is used. The small size is marked 3½ x 6 and A. Fig. 5 is a White Card with a reference to the Transactions of this Society. Fig. 6 is a Green Card with a reference to a thesis on the subject, written by a student of the Institute. The number in this case refers to the thesis, all of which are bound and in the Department Library.

14 We next come to a number of amber cards. Passing these over we come to the middle tab cards, dividing the subject into smaller groups. Fig. 7 shows the one for Design. Back of this we find an amber card, Fig. 8. Fig. 9 shows a blue card used for authors' index in connection with Book Reviews only. Fig. 10 shows a sample of

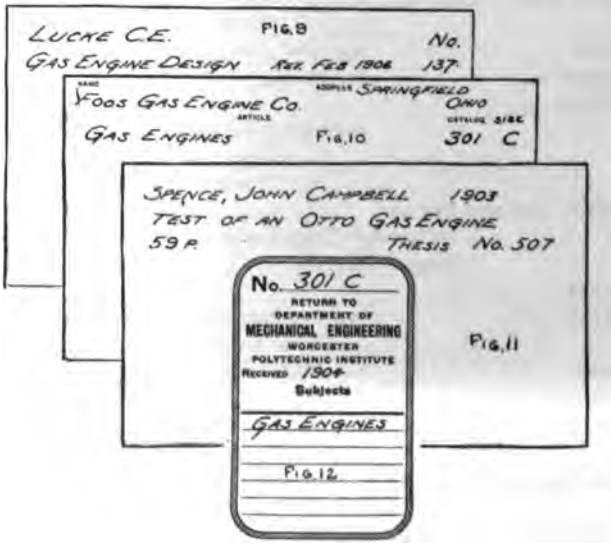


FIG. 9 BOOK REVIEWS—AUTHORS' INDEX (Blue)
FIG. 10 MANUFACTURERS' INDEX (White)
FIG. 11 THESES—GRADUATES (Cream-White)
FIG. 12 CATALOGUE LABELS (White)

the cards as found in the Manufacturers' Directory. Fig. 11, a sample of the cards from the Graduates' Index giving the thesis number of each. Fig. 12 is a sample of the labels used on the catalogues.

15 This file has been in constant use for nearly three years and has proved entirely satisfactory in its operation and maintenance. There are at present on file about 5000 references, about 1000 catalogues and 165 book reviews. The question naturally presents itself: Should a file of this kind be permitted to take on yearly growths without some systematic elimination of the less valuable material? By aiming from the start at select references, it is hoped to restrict this

growth. Aside from this, there seems to be no feasible way of ing useless material except to depend on the judgment of the specialists of the Department who use the index who can easi out useless references.

ABRASIVES — See Grinding Materials
ACCELERATION — See Mechanics
ACCIDENTS — See Failures; Legal Notes; Insurance—Liability; Safety Devices
ACCOUNTING — See Shop Management
ACCUMULATORS — See also Hydraulics; Intensifiers; Pumps
  Pressure Tanks
ACETYLENE — See Gas
ADVERTISING — See Selling
AERONAUTICS
AIR — See also Aeronautics; Liquid Air; Thermodynamics
  Flow
  Resistance — See also Friction; Railroads—Train Resist; Wind Pressure
AIR BRAKES
AIR MOTORS — See Pneumatic Tools; Wind Mills
AIR PUMPS — See Pumps—Air
AIR WASHING — See Heating and Ventilation
ALCOHOL — See also Fuels—Tests; Liquid Fuels; Gas Engines—Alcohol
  Cost
  Manufacture
ALLOYS — See also Materials of Const.; Brass; Bearings—Materials; Bronze; Steel Alloys; Aluminum—Alloys; Pattern Metals; Solder
  Acid Resistance
  Manufacture
  Properties
ALUMINUM
  Alloys — See also Steel Alloys; Bronze
ALUNDUM — See Grinding Materials
AMMONIA — See also Refrigeration
ANEMOMETERS — See also Air—Flow
ANNEALING — See Heat Treatment
APPRENTICES
  Education
  Papers
  Miscellaneous Mfg. Plants

ARBOR PRESSES
ARBORS — See Small Tools
ASBESTOS — See Packing
Pipe Coverings
ASPHALT — See Floors
ASSOCIATIONS
Buildings
AUTOMATIC MACHINES — See also Screw Machines—Automatic
Envelope Machinery
Gear Cutters
Looms, etc.
AUTOMOBILES — See also Clutches
Cost of Operation
Design
Electric
Gasolene (See also Carburettors)
History
Ice
Industrial
Manufacture
Miscellaneous
Patents
Radiators
Regulation
Shock Absorbers
Steam
Testing
Tests
Transmission Gear (See also Variators)
Fire Engines
Speed Indicators
Traction
Tires
Wheels
AXLES
BABBITT — See Bearings—Materials
BALANCING — See also Steam Engines—Balancing
Gas Engines
Steam Turbines
BALLS — See also Bearings—Ball
BAND SAWS — See Woodworking Machinery
BEAMS — See also Concrete Construction
Testing
Tests
Girders
Mechanics
BEARINGS — See also Lubrication
Ball
Design
High Pressure
High Speed
Knife Edge
Manufacture
Materials for (Alloys) — See also Materials of Construction
Roller
Conical
Tests
Thrust
Friction
Gibs
Hangers

BELLS
BELT DRESSING
BELT DRIVES — See also Belts
  Compound or Rider — Belt Dressing
  Design — Countershafts
  Quarter Turns — Power Transmission
  Tests—For Strength Tests, see Belts—Tests — Speed Cones
  Testing
BELT LACING MACHINES
BELTS — See also Belt Drives
  Cotton — Belt Dressing
  Fastenings
    Lacing
    Splicing
  Leather
  Life of
  Manufacture
  Rubber
  Tests—For Power Tests, see Belt Drives—Tests
BENCHES — See Machine Shops—Equipment
  Pattern Shops
BENDING MACHINERY — See also Presses—Benders
BICYCLES
BINARY ENGINES — For Waste Gas Engines, see Gas Engines
BINS
BIOGRAPHY
  Educators
  Engineers
  Inventors
  Manufacturers
  Scientists
BLAST FURNACES — See also Metallurgy
  Design
  Practice
  Production
BLOCKS — See Hoists
BLOWERS — See also Blowing Engines
  Design — Compressors
  Exhaust
  Fan
  Manufacture
  Positive
  Testing
  Tests
BLOWING ENGINES — See also Compressors
  Blowers
BLUE PRINTING
  Apparatus
  Positive Process
  Receipts

BOILERS — See also Heat—Radiation
Circulation — Insurance
Construction — Pipe Coverings
Cost of Operation — Power Plants
Design — See also Rivets — Radiation
Riveted Joints — Tube Cleaners
Bracing — Tubes
Stay-bolts — Valves
Water Columns
Explosions — See also Explosions
Feed
Automatic
Flash
Flues
Furnaces — See also Combustion
Flue Gases
Furnaces—Smokeless
Grates
Pyrometers
Stokers
Incrustation — See also Water—Purification
Locomotive — See also Locomotives
Marine — See also Marine Engineering
Design
Fire Tube
Water Tube
Manufacture
Oil effect
Operation
Portable
Safety Devices — See also Safety Valves
Fusible Plugs
Testing — See also Flue Gases
Calorimeters
Tests
Theory
Water Tube
BOILER COMPOUNDS
BOLT CUTTERS
BOLTS and NUTS — See also Fastenings
Hardware
Design
Manufacture
Tables
Tests
BOOK REVIEWS — See Blue Cards under main titles
Book Reviews are numbered consecutively in the Book Review Drawer
Authors names are given in the Directory Drawer

BOOKS — See also Hand Books
BORING BARS
BORING MACHINES
BORING MILLS — See also Machine Tools
  Design
  Tests See also Power Consumption
BOXES — See Bearings
BOXING — See Shipping
BRAKES — See also Air Brakes
  Automatic — Cranes—Brakes
  Band — Dynamometers—Absorption
  Design
  Electric
  Tests
BRASS (COPPER ZINC ALLOYS) — See also Materials of Construction
  Tests — Extruded Metal
BRASS FOUNDRY
  Equipment See also Furnaces
    Crucibles
  Practice
  Miscellaneous Plants
BRAZING — See also Solder
BREAKERS — See Foundry Equipment
    Mining Machinery
BRICK — See also Fire Brick
    Foundations
    Mill Construction
BRIDGES
  Draw
BRIDGE PLANTS
  Equipment
  Miscellaneous
BROACHES — See Small Tools—Broaches
BRONZE — See also Materials of Construction
  Aluminum See also Aluminum—Alloys
  Gun Metal
  Manganese
  Phosphor
  Tests
  Tobin
BRUSHES
BUCKETS — See Coal Handling Machinery
    Water Turbines
    Water Wheels
BUFFERS — See also Dash Pots
BULLDOZERS — See also Forge Practice
    Forge Shops
BUNKERS — See also Coal Handling Machinery
    Power Plants
    Coal-Storage

DISCUSSION

PROF. L. P. BRECKENRIDGE While the general scheme, as outlined in this paper, is in the highest degree commendable, the system of indexing seems entirely inadequate. Alphabetical indexing is, or should be, a thing of the past except for indexes of limited scope. The decimal system is superior in every respect, and is rapidly coming into use among engineers and engineering concerns.

2 For some years the Mechanical Engineering Department University of Illinois, has used an extension of the Dewey decimal classification with the most gratifying result. It keeps up a card index of current periodical engineering literature which now contains 20,000 cards. All these are indexed according to the decimal system. The same system is used for indexing catalogues, blue prints, photographs, lantern slides, etc.

3 In brief the advantages of the decimal system are:

(*a*) It groups allied subjects under one class number whereas the alphabetical system scatters them through the twenty-six letters of the alphabet.

(*b*) It prevents ambiguity and makes cross reference practically unnecessary.

(*c*) It is flexible and capable of indefinite extension.

4 Several years ago, the Mechanical Engineering Department, recognizing the value of the decimal system, prepared an extension of the Dewey System for Mechanical Engineering. This has passed through four editions. A fifth edition containing extensions for all branches of engineering is now ready for the press and will appear in the near future.

PROF. WILLIAM KENT Messrs. Bird and Smith have done a service to the Society in publishing their valuable index. I have no time at present to study it in detail but hope to do it sometime in the future and for some years I have been hoping to write a paper on the same subject myself. I wish that special attention would be called to paragraph 6 concerning standard sizes for catalogues. I wish there could be some way of fining any manufacturer who brought out a catalogue of any other size than one of these standards. A confusion of size in any shelf of catalogues gives rise to no end of trouble to everyone who attempts to keep a file.

MR. LUTHER D. BURLINGAME I have read the paper on "A Mechanical Engineering Index" with much interest and feel that it

shows an appreciation of the ne for as is described, and also an understanding of t ways and means required for supplying such needs.

2 For many years we have been working to adapt to our needs the various indexes required in our drafting and engineering departments at the Brown & Sharpe Co., and among the many forms of indexes which have had attention that for trade catalogues has had its due share.

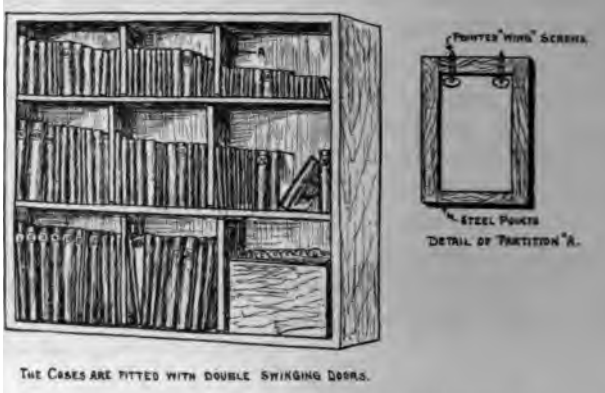


FIG. 1 SHOWING THE DIVISIONS DESCRIBED

3 At first we filed the catalogues in drawers with divisions for groups of four sizes and used a card index for reference, much as described in the paper under discussion. What we now consider a better method is to file the catalogues vertically in cases, as shown in the sketch herewith, the catalogues being arranged in order by sizes, and numbered from 1 up. In starting a new index numbers could be skipped to allow for additions. Even in our case where, when we started this system and had thousands of catalogues in index, we allowed some spaces. When the size of a new catalogue is such as to bring it between two consecutive numbers, as between 41 and 42, it is numbered 41a, the next one of this size 41b, and so on through the alphabet, thus allowing for at least 26 additions between any two consecutive numbers.[1]

4 In addition to indexing the talogues under the name of the firm, a general cross index of subjects is made something in the nature of a "topical index." Thus, the sample card "Gear Cutting Machines"

[1] When the catalogues are too thin to put the numbers on the back, they are put on the side where they will readily be seen as the catalogues are handled

is the second card of a set on this subject, giving the names of the firms, the dates of catalogues and their index numbers.

5 There are many circulars, thin catalogues, photos, and advertising clippings that cannot be satisfactorily filed with the regular catalogues. To provide for such, boxes are used which fit into the catalogue cases and are subdivided alphabetically and with special headings by means of tab cards. These are of a size to take 6″x 9″ leaflets with a generous margin, and anything larger is folded to that size. Any clipping so small as to be in danger of being lost is gummed to a piece of blank paper 6″ x 9″.

FIG. 2 INDEX CARDS

6 A charging system is used to know where to locate catalogues that are out. All new catalogues come to and are distributed from a common center, going the rounds of those who should know of their contents before being filed for future reference.

7 Trade literature is indexed by a system independent of the catalogues.

MR. A. B. CLEMENS The index of Messrs. Bird and Smith seems to be generally well adapted to the purpose for which it was intended. The difficulties that present themselves in the preparation of such an index are many, and a scheme that is suitable for an existing set of conditions may be found impractical and cumbersome as the conditions change. The ideal system of indexing must meet constantly changing conditions and should be so flexible that additions of new

subjects and further subdivisions of old subjects can at any time be made without affecting other portions of the system.

2 Herein it seems to me lies a weakness in the system presented. It does not lend itself readily to expansion. This seems to be the greatest objection to all alphabetical systems. Professor Breckenridge says that alphabetical indexes are, or should be a thing of the past. This is, I think, the opinion of most men who have had experience with such indexes. Professor Breckenridge suggests the Dewey decimal system with some changes, and while this is undoubtedly a step in the right direction, it is found wanting in that it provides for only 10 divisions under any one head. The range may readily be extended by using letters of the alphabet instead of figures, thus making provision for as many divisions of any subject as there are letters in the alphabet. Subdivisions may be worked out as in the Dewey system, using either letters or figures, as may in any case seem most desirable.

3 Such a system, with a corresponding set of headings, was devised by Mr. J. J. Clark, Manager of the Textbook Department of the International Correspondence School, and is now in use in that institution. It has been found that it lends itself readily to the indexing of any kind of matter; books, clippings, blue prints, catalogues, or any other material, whether filed in a library or scattered among different departments and buildings, and it may cover apparatus, models, or material of any kind. This is found very advantageous, but the greatest advantage lies in the fact that it provides for a growth from a small index, covering a small amount of material, to an index of large proportions, and also for continued subdivision of any subject as such subdivisions may become desirable.

4 Another point of weakness in the system presented by Messrs. Bird and Smith, is the frequent use of cross references; for instance, suppose that it is desired to find matter relating to Lubrication. We find opposite "See also Bearings, Friction, Lubricators, and Lubrication." After looking through the material indexed directly under Lubrication and failing to find the desired information, we turn to the "See also Bearings," there we find a little more material and here again find "see also Lubrication," "Friction," "Gibbs" and "Hangers." We may then turn to one of these "See also's" and look further, and so on until we have exhausted the various lines of search indicated. It seems to me that such an index fails in the most vital point, the location of desired information in the shortest possible time. This difficulty could no doubt be remedied by using file cards more freely and indexing directly under each head all the matter

relating thereto. This may necessitate the indexing of some matter under a number of different heads, requiring the expenditure of a little more time in the preparation of the index, but saving many times the added cost when searching for needed information.

MR. HENRY HESS No happier definition of "Index" than that given by Messrs. Bird and Smith as a "mechanical memory" can well be found. No doubt also that the index arrangement devised and adopted by them for the purposes of the Worcester Polytechnic Institute is a very good one. But is not the subject one that merits a much broader treatment?

2 Conceive that the various scientific institutions of the world agree on a definite uniform classification of all knowledge—that each indexes all matter in its libraries under the same heads that similar matter would be indexed by every other—that each member of such institution indexes his particular collection similarly. Conceive further that all of these indexes be collected and copies distributed to all of the various institutions. The result would be an enormous simplification in making available to every worker in every field the recorded experience of every other laborer along allied lines. Instead of his being obliged, as now, to laboriously wade through the catalogue of this, that, and the other library—each one probably arranged along a plan sufficient unto itself—he would be under the need of consulting but a single index and with the certainty that, so far as human ability could compass it, he would there find recorded every source of information.

3 Undoubtedly the conception seems at first sight almost impossible of realization. The difficulties of the work itself are, however, not by any means insuperable; rather, it is the difficulty of getting the various scientific bodies to even agree to take up the plan. Possibly the best way to get the thing done is to make an actual beginning.

4 The various chief engineering associations of the country now united under the one roof of this most fitting habitation provided by a munificent generosity have already merged their individual libraries into one of far greater usefulness. In what more far reaching and widely beneficial way could they signalize and emphasize their realization of the importance of unity of endeavor, than by appointing a committee to plan and start a universal index such as that suggested?

5 An honored ex-president of this Society and leader in original work along sociological and engineering lines, Professor Sweet, once happily defined the usefulness of engineering calculations as providing

"a basis of departure." It is with this in mind that I present the following outline for discussion.

6 The Dewey system of classification is probably familiar to most of the members. It contemplates the division of all knowledge into certain main heads, the further subdivision of each main head under subheads, and so on indefinitely. Its author makes each group consist of ten heads, one of these a collective one to take all matter not included elsewhere. To each head a number is assigned as, for instance, No. 6 Useful Arts, No. 5 (1st subhead) Engineering, No. 4 (2d subhead) Mechanical Engineering. These are not Dewey's numbers, but merely assigned for explanation. Any item pertaining to mechanical engineering would thus be found under 654. Steam Engineering would be a further subhead, say No. 7, and would be found under 6547, and so on indefinitely. The division into ten heads is, of course, an arbitrary one and desirable simply because ten is the basis of our system of numbering. To my mind this very arbitrariness of classification is a distinct advantage because from the very beginning it does away with any attempt at a logical classification. Logic is a mental process and its application will always and necessarily be along the lines of each individual's mental processes. These latter are as diverse as are the lines of work followed, further differentiated by the personal equation. Even absolutely similar matter presents itself to different individuals from different viewpoints, so that each would group it otherwise with relation to cognate matters, and yet each grouping might be strictly logical.

7 As against the alphabetical arrangement, the Dewey plan possesses the advantage of being as international as is our Arabic number system. Assume for instance, that a German engineer wanted to inform himself on the subject of chain hoists, including also the American and English developments. His German index guide would inform him that 654-927-34 would cover everything on that subject in every language. Under an alphabetical arrangement he would first have to consult dictionaries to get the various foreign terms and only then—provided he were fortunate—he would be in the first stage of his still hunt. If, unfortunately, he might find that his dictionary translated "Flaschenzug" as "bottle" for "Flasche" and "pull" for "Zug," ergo "bottlepull." Not finding that in the indexes he would probably ask a friend for a synonym for "bottlepull" and get the obvious one of "corkscrew." The obliging library attendant passing out to him all matter referring to corkscrews would probably not deeply impress him with the value of an index scheme that resulted in such "carrying of coals to Newcastle," as giving a native of the Fatherland information about corkscrews.

8 One very decided advantage of the numerical classification lies in the readiness with which cuttings, extracts, etc., can be filed in numerical order. Data in book form would be stored on shelves, while catalogues, pamphlets, cuttings from papers, etc., would be filed in a limited variety of receptacles; letter symbols would be used to designate the character of the filing device.

9 All information on a given subject would thus be quickly found, distributed, at the worst, through only as many places as there were different classes of files, instead of having to be laboriously gathered together from many locations. It would be necessary merely to pick out all matter bearing the same numerical symbol. Its proper distribution after use would be equally simple and expeditious as would be also the proper interpolation of new matter from time to time. The gathering, distribution, and interpolation could be left to very subordinate help, whose chief qualification would be an ability to read numbers.

10 It would be of great advantage to have the various filing receptacles of standard size and design, possibly differing only in costliness to suit various purses; this would be in line with the already widely adopted size standards of catalogues, papers, etc., first advocated by this Society; it would also insure the uniformity of these place symbols, and so permit of the amalgamation of various collections of mere routine and almost mechanical distribution.

11 To burden a committee with the enormous task of grouping all knowledge under number symbols would result either in never even getting as far as its formation or its early resignation. But such burden would not be at all necessary. A start has already been made by the fairly wide adoption of a Dewey classification in many libraries. With this as a basis, the committee would confine its task initially to interesting as many members as possible in the task of revision and extension by each of a subgroup, to collecting the contributions, to forming subcommittees for the future consideration of this matter, and finally to a boiling down of the whole.

12 It may be fairly assumed that enough capable and public spirited men can be found to give their services without charge; still much clerical work and other expense would be involved. The needed funds could be secured by subscription of outright gifts and as the work progressed, by partial advance payments for copies of the index, the final payments to be made on delivery. Members editing engineering papers and magazines should be moved to print the index symbol with every article, to refer their annual alphabetical index to these symbols and to add an index giving the different articles under

each symbol. Some might possibly consider work of this character as beyond the scope of the Society, but certainly not if the purpose of its organization, broadly to further the interests of the engineering profession, be remembered.

13 If precedent is considered of value, that set by the Verein Deutscher Ingenieure—probably the largest engineering society in existence—in getting out an international technical dictionary, its "Technolexikon" will serve. It would be eminently desirable could the committee secure from the very outset the formation of and coöperation with similar committees from other engineering societies —those sharing in the administration of the Engineering Societies' Building would probably be easiest to interest—but, whether or no, the important thing is to make a determined start. The indubitable advantages of such an index issued by the Society for its field of Mechanical Engineering in detail must, with time—be it long or short—win wide and growing support.

14 Whether the Dewey classification suggested be adopted or not is immaterial, but let it be considered that of a vast body of engineers daily accumulating and more or less thoroughly indexing and classifying information, many would adopt the proposed universal index, that the most of these would be glad to respond to their society's request to bequeath their accumulations to it, that such matter would come under the control of the society libraries in an increasing flow and in a condition of almost complete readiness for absorption by mere distribution, then it must be clear that with time, the achievement of each individual worker will be made available to and benefit every other worker, and that with consequent decrease in duplication of effort, less energy will be needlessly expended and more be available for the furtherance of civilization.

THE AUTHORS Professor Breckenridge in his discussion of our paper says that alphabetical indexing should be a thing of the past, except for indexes of a limited scope. In reply to him, we would say that our index is of a limited scope, inasmuch as no subject is introduced unless it is connected in some way with Mechanical Engineering. On the other hand, however, its use is not limited to those possessing a key to the Dewey System. Anyone who can spell can readily find a given topic, and it has been our experience that a stranger has no difficulty whatever in using our index. Therefore, the main object has been accomplished—we have a system which requires neither an attendant nor a book of explanations.

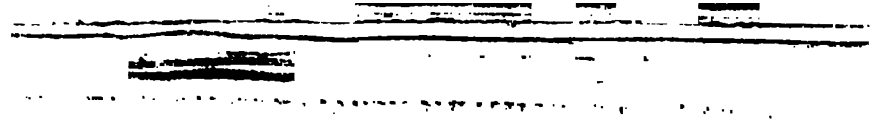
2 Our list of titles and sub-titles is similar to the Relative Index

of the Dewey System, which is also arranged in alphabetical order and differs from ours in that a number has been assigned to each title. This system of numbering is of great value in the matter of filing books and catalogues and we have adopted such a system for our catalogue file. We did not consider it necessary to use numbers on our book references, as we maintain our Department Library simply as a working library of the latest books and best authorities. All our books are numbered according to the Dewey System and can be located in the usual way by reference to the regular Library Index.

3 No system can produce a grouping which will put all the material on a given subject in one place, for the reason that all subjects are inter-related like the meshes of a net and not like the branches of a tree. And we agree with Mr. Hess that if we are to have a universal system it must be an arbitrary one. We should be glad to see some such scheme as he has suggested adopted by all engineering schools and societies, and we believe that it would be of the greatest benefit to the profession. In the meantime, we can all help in the good work if we will see that all catalogues for which we are in any way responsible are of the standard sizes, and that all books and contributed articles have logical titles, *i.e*, titles which have a definite relation to the subject matter.

4 Mr. Clemens thinks that our system does not lend itself readily to expansion. If he will stop to consider that it is a card index, and that there is a place ready for any new topic from *A* to *Z*, he will see that his criticism applies only to our list of subjects as published, which of course is fixed for the present at least.

5 In closing, we would say that this system of indexing is a part of our department organization, and we have brought it to the attention of the members of the Society, not because we think that it is the only way of indexing, but rather to let others have the benefit of our experience along this line, which we believe has resulted in a successful system.



No. 1130

IMPROVED TRANSMISSION DYNAMOMETER

By W. F. DURAND, STANFORD UNIVERSITY, CAL.
Member of the Society

1 The importance to the engineer of instruments and apparatus for the measurement of engineering quantities will perhaps serve as an excuse for bringing to the attention of the members of the Society the form of dynamometer which is the subject of the present paper.

2 At different timesd uring the past eight or nine years, the author has had occasion to use a transmission dynamometer in connection with certain investigations on the action of screw propellers. For this purpose a special form of rope or round belt dynamometer was designed and constructed which rendered excellent service. Forms of this dynamometer have been described in other engineering publications.[1] This very considerable experience with one type of service exposed the less satisfactory features of this form of dynamometer, and in the endeavor to produce a perfected apparatus, based on such experience, the design described herein was developed. (See Fig. 1, 2 and 3.)

3 In general the conditions imposed were as follows:

a To reduce internal friction to a minimum.

b To eliminate belt slip or creep under heavy loads.

c To provide an apparatus of maximum capacity for given weight of material, and, therefore, of the maximum degree of portability.

d To provide for the measurement of turning moment either by spring balance, by beam scale weighing, or by hydraulic step and pressure gage.

4 A and B are two sprocket wheels mounted on a frame XY which is carried at E by a steel spring support, after the manner of the well-known Emery steel plate knife edge. This is frictionless, and for small movements of the frame the bending stress developed is infinitely small in comparison with the other forces in play. As shown at

[1]Transactions Society Naval Architects and Marine Engineers.

Presented at the New York Meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

S S, the frame carries semicircular plates of steel fitted with a slot, either end of which engages with a pin as the frame oscillates through its permitted range of motion of about one-fourth inch at a distance of ten inches from the center of support. This permits perfect freedom of motion within this range, but prevents movement beyond to such an extent as to develop any sensible force within the steel spring supports.

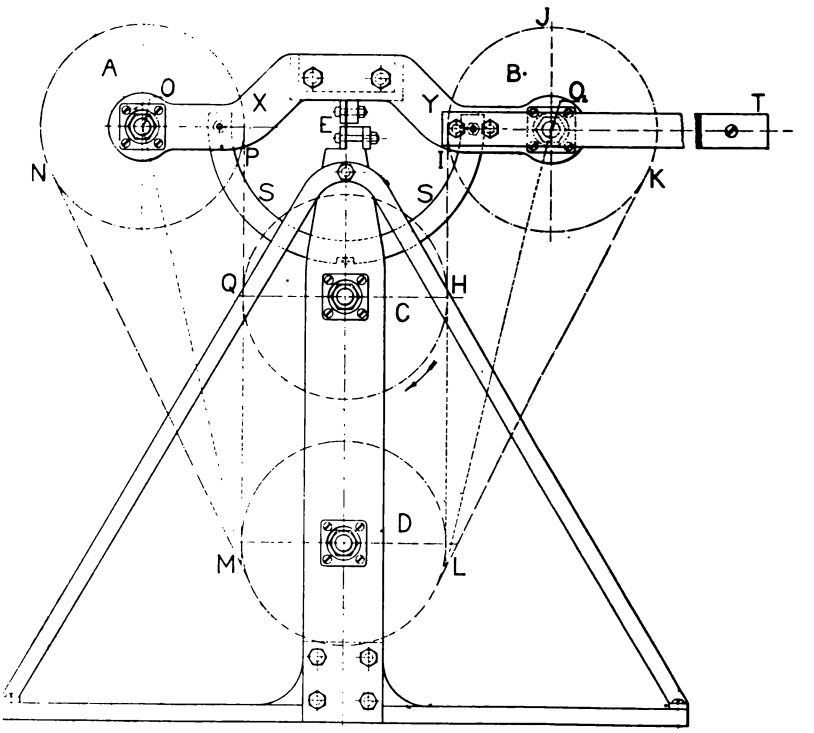


FIG. 1

5 The sprockets *C* and *D* are similar in form and size to *A* and *B* and are mounted on standards attached to the base. All sprockets are mounted on ball bearings in order to reduce friction to the minimum. Around these wheels is led a chain, the dimensions being so adjusted that with the proper length of spring for bearing at *E*, the chain throughout its length will run with the proper amount of slack for smooth and steady operation.

6 The similarity between this form of dynamometer and the Tatham form will be readily noted. The present type may, in effect, be considered as a development of the six-equal-wheel form by the elimination of the two lower wheels and the substitution of chain for belt drive.

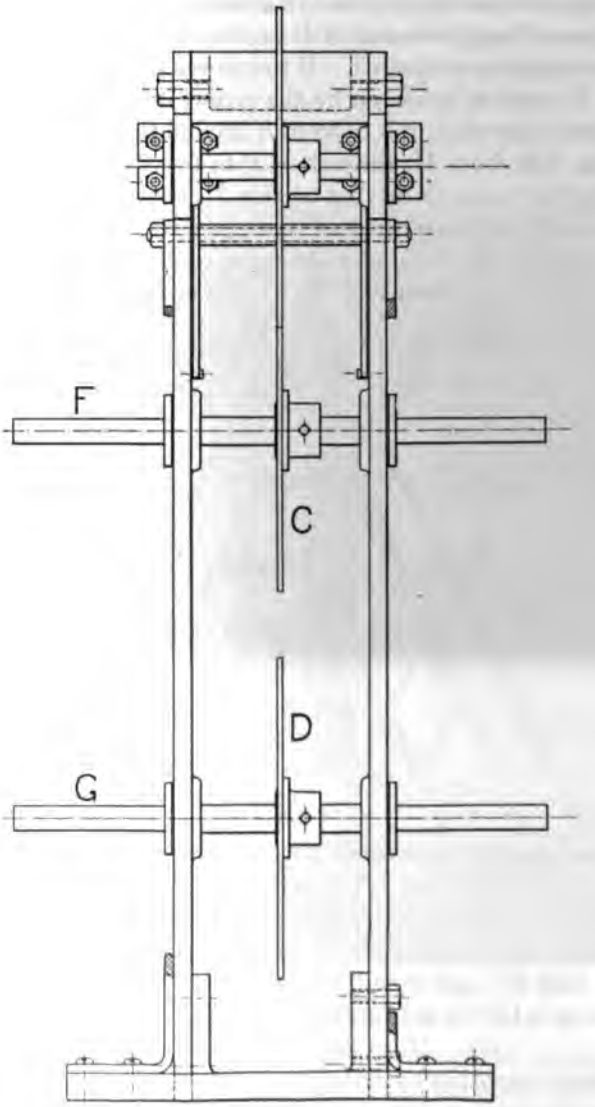


FIG. 2

7 The shafts which carry the sprockets C and D are extended carrying pulley wheels at F and G, Fig. 2, and also universal joint couplings for direct connection to a driver or follower. The power can be put in at C and taken out at D or vice versa, and on either side of the dynamometer as desired. If the power passes through from C to D, and C turns as indicated by the arrow, it is readily seen that the tight side of the chain will be from H around through $I\ J\ K\ L\ M$, and the loose side from M, through $N\ P$ to Q. Thus $H\ I$ and $K\ L$ will be under the higher or driving tension T_1, equal on both sides except for the small friction of the ball bearing on which B turns. Likewise, $M\ N$ and $P\ Q$ will be under the loose or following tension T_2, the same on both sides except for the friction of the ball bearing on which A runs.

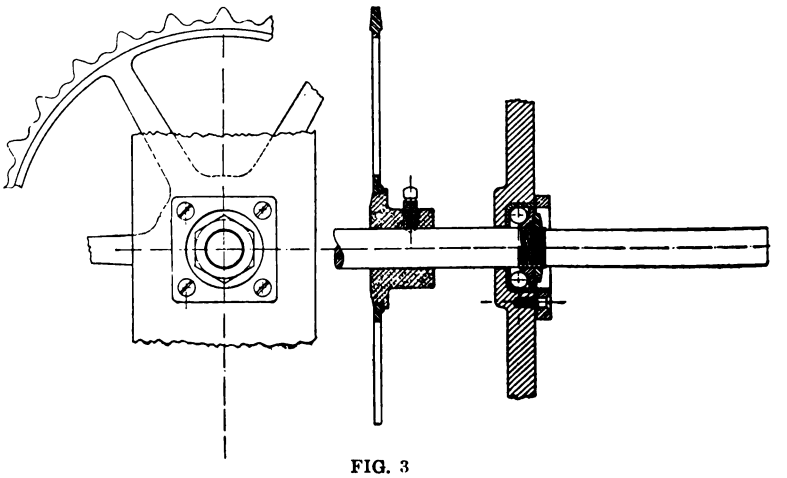


FIG. 3

8 Disregarding these small frictional resistances, the two tensions T_1 will have the resultant $2T_1 \operatorname{Cos} \theta$ directed along the line $O_1 L$, while the two tensions T_2 will have the resultant $2T_2 \operatorname{Cos} \theta$ directed along $O M$. The components of these forces perpendicular to the line $O\ O_1$ will be in each case $2T_1 \operatorname{Cos}^2 \theta$ and $2T_2 \operatorname{Cos}^2 \theta$. Denoting the distance $O_1 E$ by a we have for the net turning moment about E

$$M_1 = 2a\ (T_1 - T_2) \operatorname{Cos}^2 \theta$$

9 Again denoting by r the pitch line radius of the sprockets, we have for the power taken off at D the turning moment

$$M_2 = r\ (T_1 - T_2)$$

$$\text{Hence } M_2 = \frac{M_1 r}{2a \operatorname{Cos}^2 \theta}$$

$$\text{and work per } mt. = 2\ \pi\ N\ M_2 = \frac{\pi\ N\ M_1 r}{a \operatorname{Cos}^2 \theta}$$

10 Obviously the two tensions T_1 on the right, acting against the two tensions T_2 on the left will determine a moment tending to depress the end T of a lever attached to the frame XY. If we denote ET by h and the force at T required to balance the moment by F we shall have

$$M_1 = Fh \text{ or}$$

$$\text{Work per } mt. = \frac{\pi N F r h}{a \operatorname{Cos}^2 \theta}$$

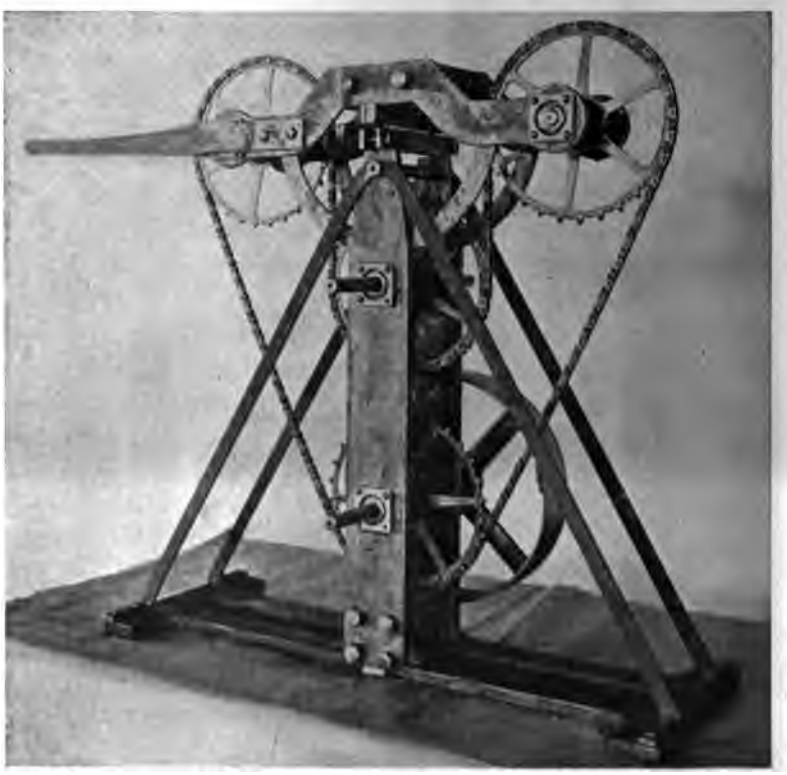


FIG. 4

11 By careful measurement of the dimensions of the dynamometer the relation between the power transmitted and the observed values of N and F can be determined. As in all cases involving the use of such apparatus, however, it will be more satisfactory to calibrate directly by mounting a friction brake on a belt wheel attached to the delivery shaft and noting the relation between brake readings and the values of the force F. Such a calibration will of course serve to eliminate all

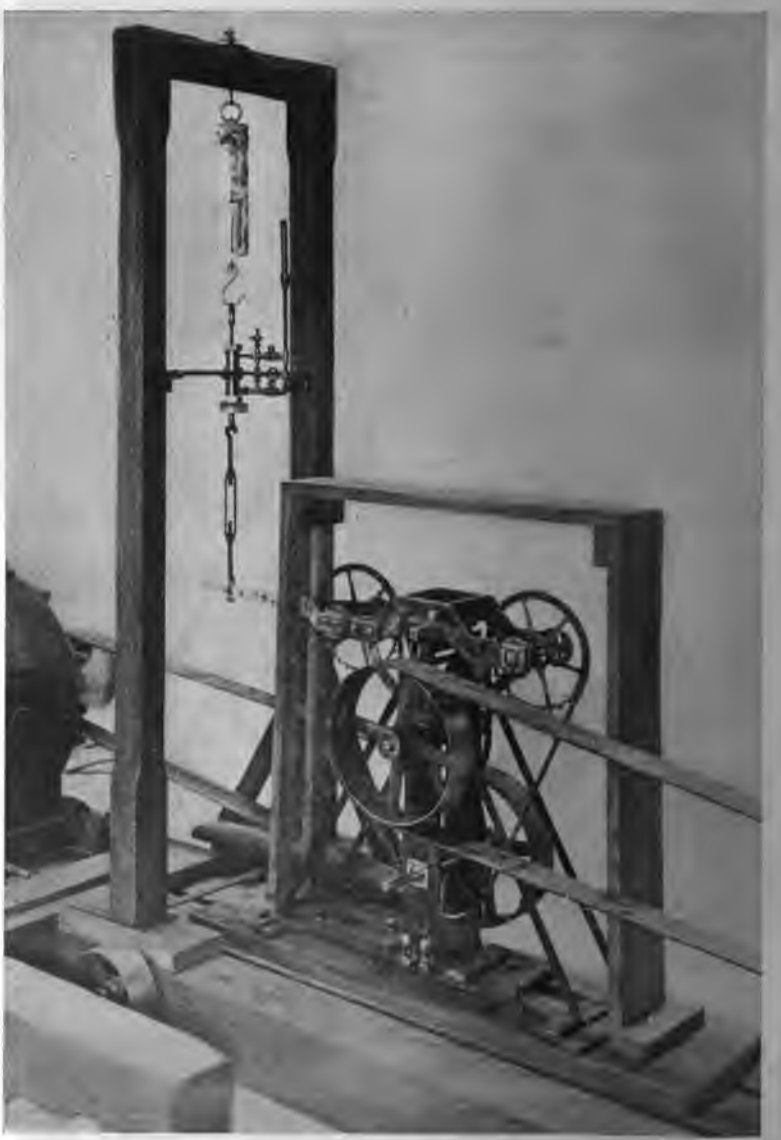


FIG. 5

friction between the points of intake and delivery, or in the dynamometer itself, and will thus serve to relate correctly the force records as measured by F with the actual power delivered.

12 In the case of the dynamometer under present notice the relation in question was determined by both methods—measurement and computation, and by experimental calibration. The difference should then be an indication of the amount of power absorbed by the friction of the apparatus. The tests indicated but slight friction in the chain and bearings, which might have been expected from the character of the design and construction.

13 The chief dimensions of the dynamometer shown in the figures are as follows:

Diameter of sprocket wheels	9 in.
Diameter of shafts	$\frac{3}{4}$ in.
Size of chain	$\frac{3}{10}$ in. wide
Height over all	30 ins.
Width of base	12 ins.
Length of base	30 ins.

14 The capacity of the dynamometer as constructed was intended to run to some 5 or 6 horse power. Certain experiments requiring somewhat more power presented themselves, however, and the dynamometer was successfully used up to about 12 horse power, but this is more than was intended and is beyond the proper limit for sprockets, chain, and bearings of these dimensions.

15 In terms of revolutions no trouble was experienced in running the dynamometer up to 800 or 900 r.p.m., speeds which would with difficulty be realized with a rope or belt driven dynamometer.

16 A larger dynamometer of the same type is under present construction in which 12 inch automobile sprockets and 5000 pound sprocket chain will be used, and with which a capacity of about 50 horse power should be realized.

DISCUSSION

PROF. J. J. FLATHER. I have been greatly interested in reading Professor Durand's paper on "An Improved Transmission Dynamometer" and am pleased to note that the machine presented offers an excellent means of accurately transmitting power without the usual expensive and frequently cumbersome apparatus often found in our laboratories.

2 This machine, as the author states, is a modification of the Tatham transmission dynamometer, described in the "Journal of the Franklin Institute," December, 1882, and November, 1885. This type of dynamometer is free from the objection so common to many other forms; namely, the effect of centrifugal force under high speeds. The capacity of the present machine is much greater than one would expect and its compact and light form renders it available for a variety of work where a heavier machine would be very troublesome.

3 The introduction of ball bearings in the main shafts may cause trouble. With light loads and high speeds they may be expected to give very satisfactory results, but the writer would prefer roller bearings for this work. The convenience of an overhanging pulley for receiving and delivering the power is probably sufficient to warrant its use, although this arrangement possesses some disadvantages which might give erroneous results under certain conditions. However, any additional outside bearings would materially increase the size and weight of the apparatus and thus make it less available for general work. The use of the Emery flexible plate instead of pins or knife edges is to be commended. While a hardened steel knife edge in the present case would probably not cause any appreciable error, the use of the plate with limiting stops produces no friction at all and is to be preferred. The simplicity of design and ease of construction are features which will appeal to the engineer outside of the laboratory, for a very satisfactory machine of this type can readily be made almost anywhere at small expense and in a short time. This machine is certainly a great improvement on the ordinary belt transmission dynamometer.

THE AUTHOR Regarding the comment on the paper, no closure is required other perhaps than reference to the remarks by Professor Flather regarding ball bearings. I quite agree that for larger capacities a roller bearing would be more durable, and in the larger design, to which reference is made, a special form of double "high duty" ball bearing is employed. It may be said, however, regarding the smaller pattern described in the paper that no trouble has arisen in connection with the bearings except when run at an excessive overload (about 100 per cent) when one or two presumably defective balls were broken, with some consequent cutting of the bearings.

No. 1131

A HIGH DUTY AIR COMPRESSOR

BY O. P. HOOD, HOUGHTON, MICHIGAN

Member of the Society

1 Large steam engines of exceptional performance have usually been connected with pumping machinery, the definite load removing some of the limitations imposed upon the designer of engines for general service. This characteristic of nearly uniform work performed per stroke is possessed also by machines for compressing air and the needs of a large mine are such as to require units for this purpose of large size. In the copper country of Michigan several such compressed air plants exceed 1000 h. p. each and there is one about 5000 h. p. Fuel is confined to the better grades of bituminous coal, worth in the hands of the fireman from $3 to $4 per ton, so that economy in its use seems desirable. These facts have led some managers to install high duty machinery, and it is the purpose of this paper to report the results found in a test of a high duty air compressor installed at the Champion copper mine at Painesdale, Mich.

2 At the time of selection of this machinery Dr. L. L. Hubbard was general manager and Mr. F. W. O'Neil (Junior Member) was chief engineer. The Nordberg Manufacturing Company of Milwaukee, Wis., proposed an engine designed to use steam at 300 pounds pressure equipped with a regenerative feed water heating system.[1]

It was guaranteed that this engine should develop 180,000,000 foot pounds of work in the steam cylinders for each one million heat units used and should compress 9000 cubic feet of air per minute to a pressure of 80 pounds gage, at 76 r. p. m. This guarantee was accompanied with a bonus and forfeit clause, the amount to depend upon the results of duty trials of the engine. Geary water tube boilers were installed and practically no difficulty was experienced with the installation until at pressures above 250 pounds, when there appeared boiler troubles which made it necessary to run the plant at the

Presented at the New York Meeting (December, 1906) of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

[1] Transactions, Vol. 21, p. 181

reduced pressure of 250 pounds. Under these conditions the original contract could not be carried out, but it was desired by Mr. F. W. Denton, General Manager of the Copper Range Consolidated Company, operating this mine, to discover the actual performance of this engine under the daily running conditions of reduced boiler and air pressure and at a speed about three-fourths of that contemplated in the guarantee but sufficient for the present maximum needs of the mine. The machine had been in commission for about 17 months, was in good order, and no changes of adjustments were made for the test. The test did not include the performance of the boilers

3 The boiler plant consists of three "Geary" water tube boilers, each brick set, and over 42 square feet of grate area.

4 Each boiler is hand fired, is credited with 2068 square feet of heating surface and has 112 four-inch tubes 16′ long connecting front and rear water legs 11½″ wide. There are no baffles in the double drums Gases pass through a Green economizer and motor driven fans to a short stack. Standard hydraulic pipe fittings are used.

DESCRIPTION OF THE ENGINE

5 The machine consists of four horizontal engines placed side by side, numbered for convenience 1, 2, 3, and 4. The high pressure engine, No. 1, has a cylinder diameter of 14.5″ with poppet valves connected to a governor, limiting the speed and also the maximum air pressure produced. No. 4 is the low pressure engine with a 54′ cylinder. The intermediate engines, No. 2 and No. 3, have cylinders 22″ and 38″ in diameter and all of these have Corliss valves, and cut off adjustable, but not connected to the governor. The several cranks pass a dead center in the following order; No. 1 outer center, No. 3 inner, No. 4 inner, and No. 2 outer dead center.

6 The main shaft carries three fly wheels, the usual eccentrics for the Corliss valve motions and for the mechanically operated air valves. It also drives an offset crank on the high pressure end to actuate poppet valves, and a cranked shaft from the low pressure end to operate auxiliaries and the special valve in the low pressure heads. Below and between the cylinders reheating receivers are placed, each supplying steam to the cylinder, the jacketed heads, and the bodies of the next succeeding cylinder. Each head of the low pressure cylinder is provided with a rotating disk valve, driven from the main shaft, the function of which is to abstract steam during expansion. Steam is supplied through 90′ of 5″ double extra heavy pipe including a "Sweet" special separator 16″ in diameter and 42″ long.

REHEATERS

7 The high pressure cylinder is jacketed with steam coming from the drip of the main separator. This is led in turn through a reducing valve to the first reheater and a second reducing valve to the second and third reheaters, and then is delivered through a float trap to one of the series of feed water heaters.

FEED WATER HEATING SYSTEM

8 The feed heating system connected with the engine is divided into five approximately uniform steps with the object of gradually adding heat to the feed water by steam of progressively higher temperature which has done some work.

9 Condensation from the condenser, removed by the air pump, is raised to an open oil skimming tank by another pump.

10 An automatic float valve admits the feed to the preheater, where it gains in weight and temperature by contact with the exhaust from the low pressure cylinder. The feed is raised by a pump to an elevated heater where it meets steam drawn during expansion through a special valve from the low pressure cylinder. By gravity the feed falls to a heater receiving the discharge from the low pressure jacket line which came from the third receiver. A second pump transfers the feed to a heater receiving the second intermediate jacket water and the discharge from the trap on the reheater line.

11 Pumped again to the last heater, the feed meets steam drawn through the first intermediate jacket from the first receiver. A fourth pump drawing from the last heater returns the feed, augmented in pressure, weight and temperature through an economizer to the boilers.

AUXILIARIES

12 The several auxiliary pumps are driven by oscillating levers actuated by a crank connection with the main engine shaft. These auxiliaries consist of an air pump for removing condensation from the surface condenser, a tank pump for elevating the condensation to the oil skimming tank, a pump for circulating water through the condenser, a double pump supplying water to the air cylinder jackets and spray intercooler, an oil pump for removing oil from the oil separator placed in the low pressure engine exhaust, four pumps transferring feed water from heater to heater and to the boiler, and a small air pump to charge air chambers on pump lines.

AIR CYLINDERS

13 Interposed between each steam cylinder and the guides is an air compressing cylinder. The first stage compression cylinders are attached to high and low pressure engines and the second stage cylinders are attached to the intermediate engines. All air cylinders have

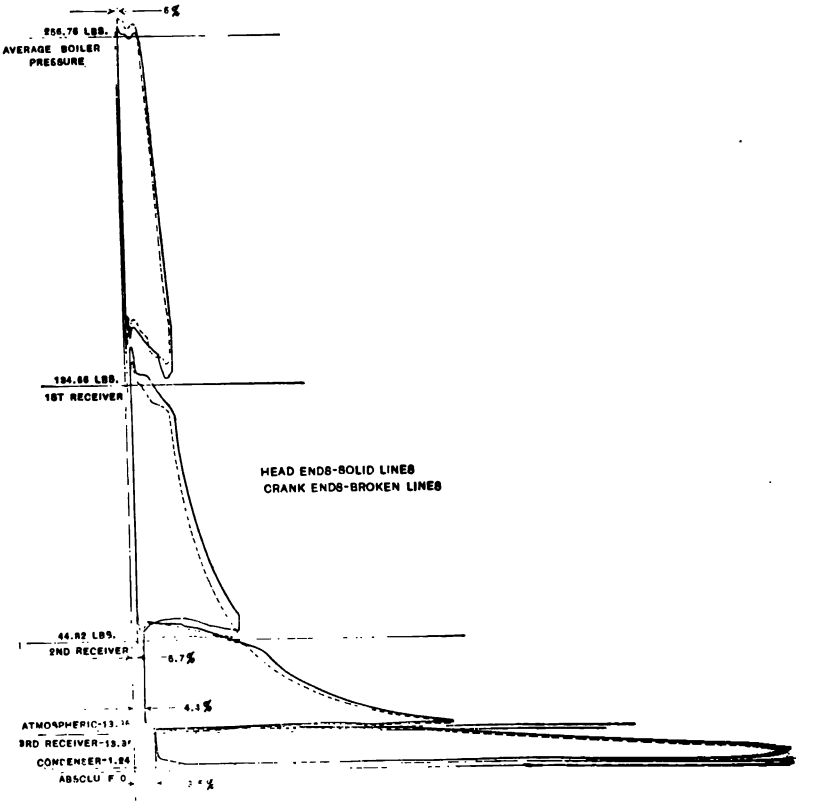


FIG. 4 COMBINED SIMULTANEOUS CARDS FROM HEAD AND CRANK ENDS OF STEAM CYLINDERS
VERTICAL SCALE 1"=15 LBS.

Corliss valves operated from eccentrics, the cylinders and heads are water jacketed, and between the two stages air is cooled in a spray intercooler. Air is admitted to the first stage cylinders through short lengths of pipe from without the building and is discharged to a receiver before entering the distributing system.

AUXILIARY PIPING

14 Air chambers on all pump lines are piped to receive compressed air when needed. All heaters are connected by small piping to the condenser to remove air which occasionally traps in them. All water jackets about air cylinders are tapped at the highest point by a system of piping, leading to the intercooler and are continuously bled

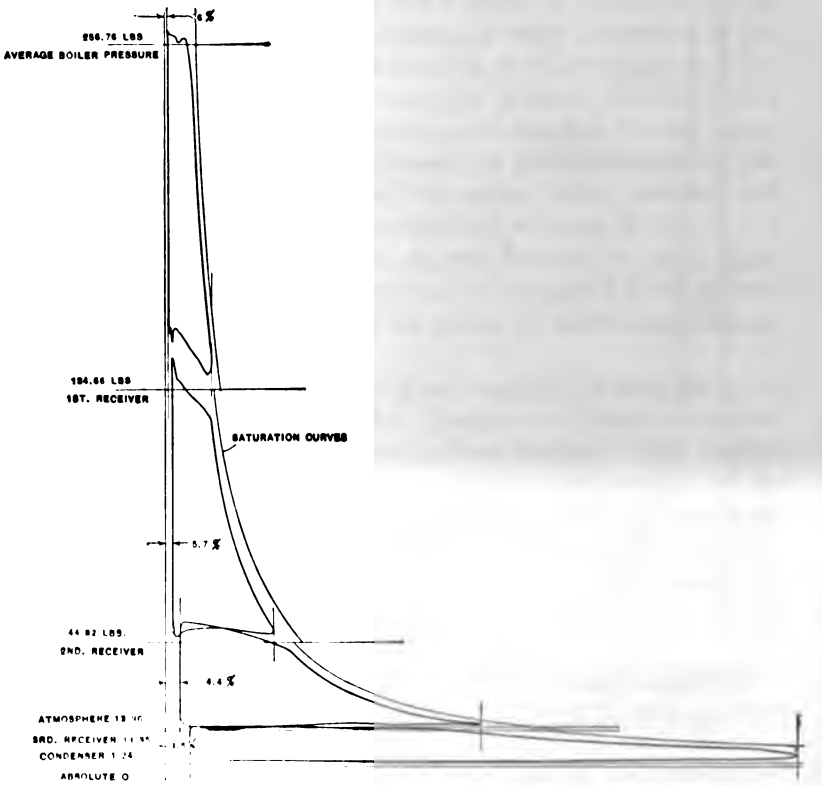


FIG. 5 COMBINED COMPOSITE CARDS FROM STEAM CYLINDERS
VERTICAL SCALE 1"=15 LBS.

to prevent pocketing of air. Steam taken from receivers to jackets passes oil separators dripped into the receivers which drain through blow off pipes. Oil for lubrication is supplied through a system of piping. Electrical connections are provided for indicators at each cylinder end.

RELATION OF PARTS

15 The whole machine occu a space 45 x 56 feet in one end of a building, there being on the level with the four engines the intercooler and skimming tank, hile below the floor are receivers, governor mechanism, auxiliary pumps, oil separator, and traps

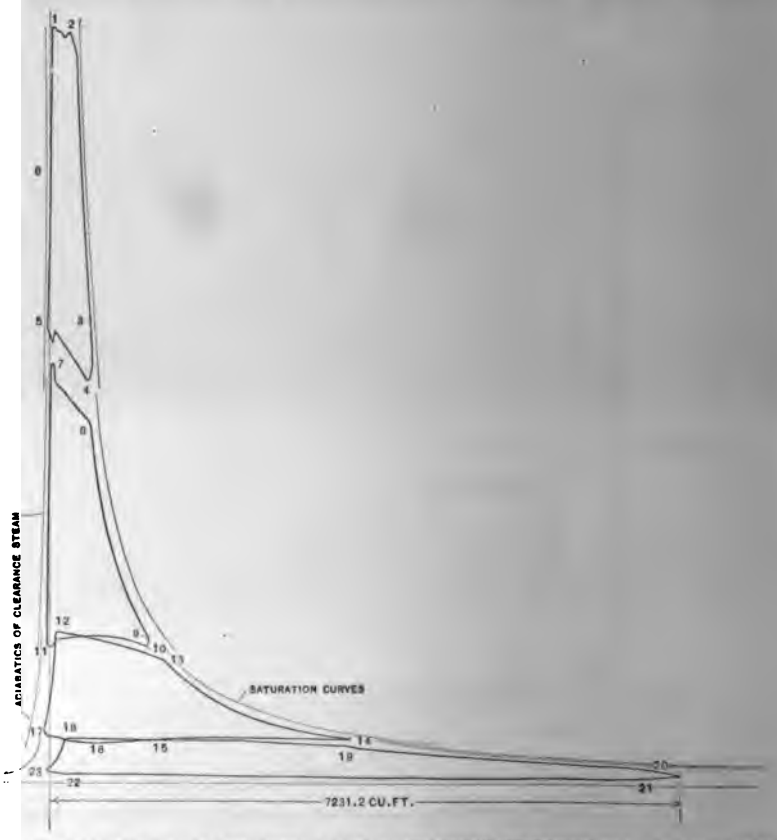


FIG. 3 COMBINED COMPOSITE CARDS SHOWING PRESSURES AND VOLUMES OF CYLINDER FEED PER MINUTE
HORIZONTAL SCALE 1"=498 CU. FT. VERTICAL SCALE 1"=15 LBS. PER SQ. IN.

The condenser and preheater extend from the basement through and above the main floor.

CONCERNING TESTS

16 The feed water leaving the last pump under boiler pressure and at a temperature of 334.5 degrees was cooled by throttling through

cast radiators immersed in cold water and delivered to weighing tanks holding about 3000 pounds each.

17 The duty was determined in a run of ten hours on March 8, by weighing the cooled water from the heaters and taking indicator cards from the eight steam and air cylinders with sixteen indicators electrically connected so that simultaneous cards were obtained. To determine the distribution of heat a similar test of five hours' duration was run on March 17, when the water coming from the condenser was weighed, as well as that from the heaters, to determine the per cent added in the heaters. To determine what proportion of this addition was abstracted from each receiver, it was necessary to adopt some method which would determine the quantity without taking anything from the system or interfering with the flow to any extent.

18 Into each line sending wet steam to either reheater or feed heater a large separator was placed, the outlet being provided with a throttling calorimeter. This arrangement is shown in Fig. 10. A glass on the side of the separator showed the rate at which water accumulated. When a small amount had accumulated it was allowed to continue its normal journey to the heater by discharging through a three-way-cock.

19 The quality of the very wet steam supplied to each place was in this way determined and the weight flowing to each heater computed from the observed temperature rise in feed heaters. This method produced no disturbance of temperatures in the feed heaters, but the numerous calorimetric determinations together with the cumulative errors of such a method make the results approximate.

PERSONAL

20 To Mr. F. W. Denton, general manager, Copper Range Consolidated Company, thanks are due for permission to publish these results and for interest shown in the work.

21 For aid in many ways in the preparation for and conduct of these several tests, acknowledgment should be made of valuable services rendered by Mr. R. R. Seeber, chief engineer Champion Copper Company; Mr. R. H. Corbett (Member), representative of the Nordberg Manufacturing Company; assistant Professor, Geo. L. Christensen, Michigan College of Mines; Mr. Wm. Richards, master mechanic; Mr. W. Stevens, foreman; Engineers D. McLeod and D. Toms, students of the Michigan College of Mines, and others who acted as observers, and to Mr. A. G. Andrew, Jr., who was employed in working up results and making drawings.

Test to Determine the Duty.

DIMENSIONS

Number of cylinder	1	2	3	4
Diameter	14.52″	22.01″	33.00″	54.00″
Length of stroke	48.00″	48.00″	48.00″	48.00″
Diam. of piston rod crank end	3½″	3½″	3½″	3½″
Net area of piston head end	165.58″	380.48″	1134.10″	2290.20″
crank end	156.64″	371.54″	1125.16″	2281.20″
Clearance	6.0%	5.7%	4.4%	3.5%
Cylinder volume head end	7948	18,263	54,437	109,900 cu. in.
crank end	7519	17,833	54,008	109,500 " "
Vol. plus clearance head end	8425	19,300	56,830	113,780 " "
crank end	7996	18,870	56,400	113,350 " "
Cylinder ratios	1.000	2.330	7.01	14.19
Horse power const. head end	1.143	2.626	7.828	15.808
crank end	1.081	2.564	7.766	15.746
Number of air cylinder	1	2	3	4
Diameter	37.22″	23.07″	23.02″	36.74″
Length of stroke	48	48	48	48″
Diam. of piston rod head end	3½″	3½″	3½″	3½″
crank end	3½″	3½″	3½″	3½″
Net area of piston hd. end sq.in.	1079.40	409.25	407.43	1051.20″
crank end	1078.00	407.87	406.06	1049.80″
Clearance ..... head end	2.65%	1.92%	1.92%	2.65%
crank end	2.57%	1.74%	1.74%	2.57%
Air cylinder ratio	1 to 2.61			

	Diameter	Stroke
Air pump	20″	12½″
Circulating pump	10⅛″	19½″
Tank pump	5″	12″
Intercooler pumps	5½″	11½″
All feed pumps	6″	7½″

Main steam pipe 5″double extra heavy.
Condenser 2700 sq. ft. of cooling surface.

TOTAL QUANTITIES, TIME, ETC.

Duration of test	10 hrs.
Water delivered from last heater as boiler feed	117,960 lbs.
Moisture in the steam near the throttle	5.74%
Factor of correction for quality of steam	94.26
Total dry steam used	111,180 lbs.

HOURLY QUANTITIES

Feed water per hour	11,796 lbs.
Dry steam per hour	11,118 lbs.

PRESSURES, TEMPERATURES, ETC.

Steam gage pressure near throttle		242.80 lbs.
Barometric pressure		28.50 ins.
Pressure in receiver	First	120.70 lbs.
	Second	30.80 lbs.
	Third	−1.24 ins.
Vacuum in condenser		25.95 ins.
Absolute pressure in condenser		1.25 lbs.
Pressure in steam jackets	No. 1	242.00 lbs.
	No. 2	120.00 lbs.
	No. 3	30.00 lbs.
	No. 4	−1.24 ins.
Pressure in reheaters	No. 1	209.00 lbs.
	No. 2	104.00 lbs.
	No. 3	73.00 lbs.
Quality of steam in receivers	No. 1	100%
	No. 2 Superheat	17°
	No. 3 Superheat	9°

TEMPERATURES

Temperature of steam fed to No. 1 engine	403.4°
Temperature of steam leaving receiver No. 1	351.2°
Temperature of steam leaving receiver No. 2	291.2°
Temperature of steam leaving receiver No. 3	216.0°
Temperature of exhaust entering preheater	114.9°
Temperature corresponding to condenser pressure	109.6°
Temperature of water fed to preheater	92.58
Temperature of water fed to heater No. 1	114.3°
Temperature of water fed to heater No. 2	173.1°
Temperature of water fed to heater No. 3	202.0°
Temperature of water fed to heater No. 4	269.7°
Temperature of water leaving heater No. 4 as boiler feed	334.5°

HEAT QUANTITIES

Heat units per pound of steam, pressure 256.8 abs.	1204.98 B. t. u.
Heat units per pound of steam supplied to engine	1157.46 B. t. u.
Heat units per pound of feed returned by engine	305.14 B. t. u.
Heat units per pound of steam charged to engine	852.32 B. t. u.

SPEED

Total revolutions in ten hours	34,167
Revolutions per minute	56.945
Piston speed in feet per minute	455.5
Speed compared to contract speed	74%

POWER

Cylinder	1	2	3	4
Indicated horse power developed in steam cylinders	181.47	256.96	275.71	275.56
Indicated horse power used in the air cylinders	220.04	222.12	226.20	214.84

Total indicated horse power, steam cylinders	989.7 h. p
Total horse power used in air cylinders	883.2 h. p
Total indicated horse power of auxiliaries	11.0 h. p
Horse power representing friction of the machine	95.5 h. p.
Per cent of friction	9.65%
Mechanical efficiency engine and compressor	90.65%

STANDARD EFFICIENCY RESULTS

Heat consumed by engine per hour per i h. .p	10,157 B. t. u.
Heat consumed by engine per hour per b. h. p.	11,382 B. t. u.
Equivalent standard coal consumption per hour assuming calorific value of coal such that 10,000 B. T. U. are imparted to the boiler per pound coal per i. h. p.	1.016 lbs.
coal per b. h. p	1.138 lbs.
Dry steam per i. h. p. per hour	11.23 lbs.
Dry steam per b. h. p. per hour	12.58 lbs.
Heat units consumed per minute per i. h. p.	169.29 B. t. u.
Heat units consumed per minute per b. h. p.	189.70 B. t. u.
Efficiency of theoretical Carnot cycle between the temperature of incoming steam and the temperature corresponding to pressure in the condenser	34.0 %
Actual heat efficiency attained by this engine	25.06%
Relative efficiency compared with Carnot cycle	73.69%
Relative efficiency compared with Rankine cycle	88.2 %

DUTY

Duty in foot-pounds of work developed per million heat units supplied to the engine	194,930,000 foot-pounds

This engine establishes a new low record for the heat consumed per hour per i. h. p., being 9% lower than that used by the Wildwood pumping engine reported in 1900.

22 The path followed by the steam through the several devices is shown in Fig. 1, while Fig. 2 shows in a diagrammatic way the flow of heat. The heat used by the engine per minute was carried by 196.578 pounds of wet steam of quality 94.26% having a value of 1157.46 heat units per pound, which weight was returned to the boilers with a heat content of 305.14 heat units, making a net expenditure of 852.32 B. t. u. per pound or a total of 167,547 B. t. u. per minute.

23 The distribution of this heat is approximated in Fig. 2 and Fig. 8. The test of the 17th showed the weight coming from the condenser, when corrected for the difference in the two tests in the heat added in the No. 4 heater, to be 69.2 % of that charged to the engine. Beginning with this quantity of 136 pounds per minute and making the additions of weight necessary to raise the feed water to the temperature observed in each heater by the addition of wet steam of the quality determined by the several calorimeters, the

computed weight going from No. 4 heater would be 8.3 pounds in excess of the known weighed amount, although the additions of heat by this computation would be in excess only 595 B. t. u. in 51,733.

24 An adjustment of the several computed weight additions in each heater was, therefore, necessary and each was multiplied by 88 % on the assumption that the cumulative errors were equally distri-

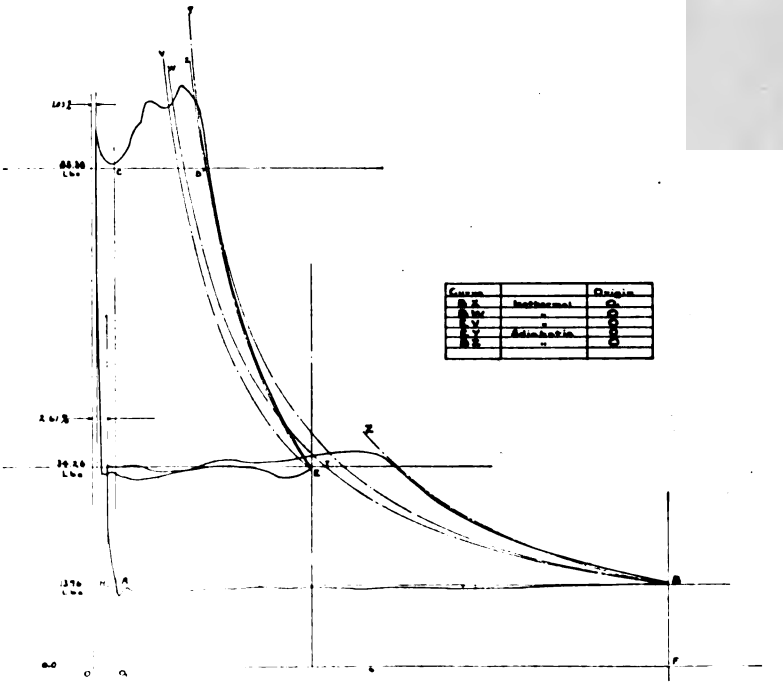


FIG. 6 COMBINED COMPOSITE AIR CARDS WITH REFERENCE CURVES

buted. This gives the following distribution of weight used per minute.

	Pounds
Steam fed to engine per minute (weighed)	196.5
Steam sent to reheater line	20.2
Steam sent through No. 1 cylinder	176.3
Steam taken from No. 1 receiver	14.9
Steam sent through No. 2 cylinder	161.4
Steam taken from No. 2 receiver	11.0
Steam sent through No. 3 cylinder	150.4
Steam taken from No. 3 receiver	4.9
Steam sent to No. 4 cylinder	145.5
Steam taken from No. 4 cylinder during expansion	7.3

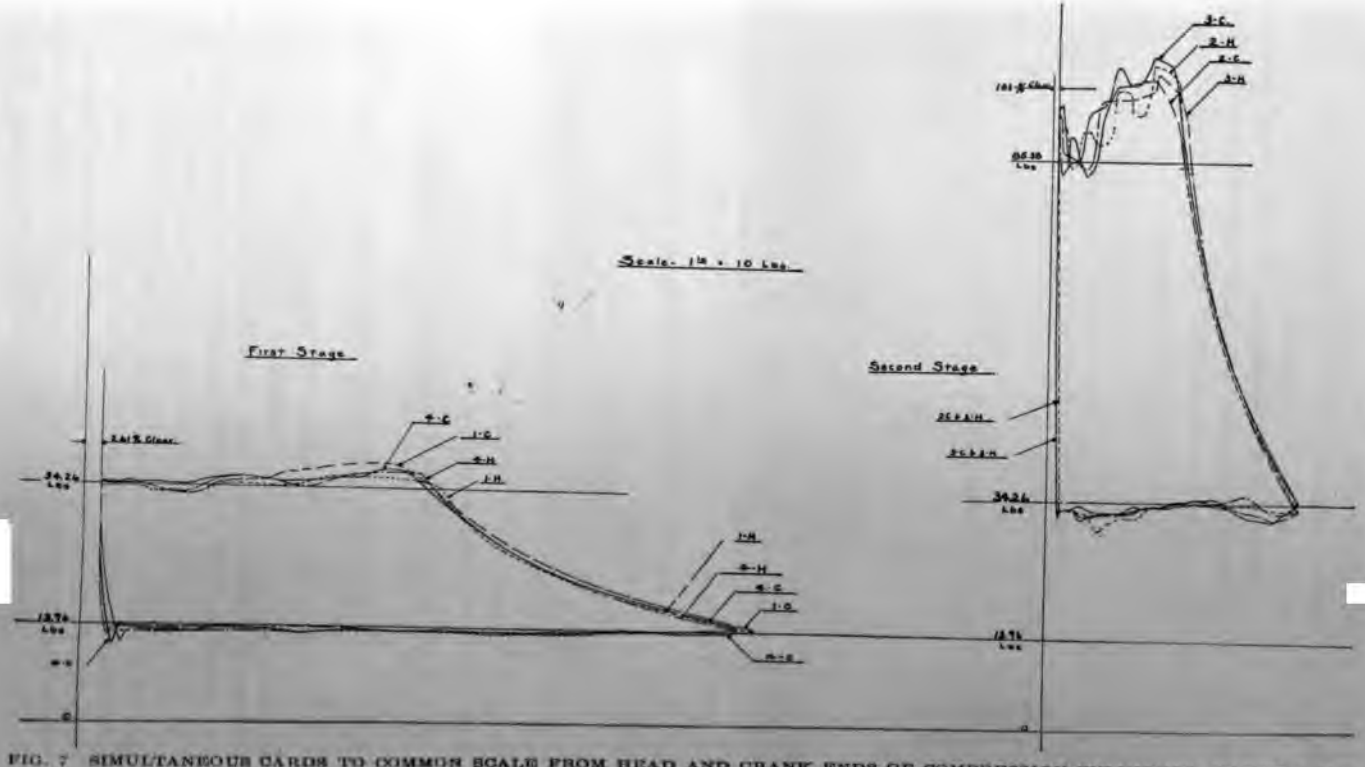


FIG. 7 SIMULTANEOUS CARDS TO COMMON SCALE FROM HEAD AND CRANK ENDS OF COMPRESSION CYLINDERS, MARCH 8, 1900

Steam condensed in the preheater	2.2
Steam sent through condenser (weighed)	136.0

25 Those adjusted weights when applied to the quantity in each feed water heater are as follows:

	Pounds
Feed water sent to preheater per minute	136.0
Added in the preheater	2.2
Feed water sent to No. 1 heater	138.2
Added in No. 1 heater from No. 4 cylinder	7.3
Feed water sent to No. 2 heater	145.5
Added in No. 2 heater from No. 4 jacket	4.9
Feed water sent to No. 3 heater	150.4
Added in No. 3 heater from No. 3 jacket	31.2
Feed water sent to No. 4 heater	181.6
Added in No. 4 heater from No. 2 jacket	14.9
Feed water sent to boilers (weighed)	196.5

26 The heat given up to each jacket was computed from the quality determinations on each side of the jacket and the weight flowing to the several heaters.

27 No measurement of the radiation from the machine was attempted because of the complication incident to maintaining the several pressures required and because the distribution of perhaps 2% of the total heat used through the numerous devices was hardly warranted.

28 One set of simultaneous indicator cards, near the mean in h. p., was selected and combined, the cards from the two ends of the cylinder superimposed as shown in Fig. 4, and from these a composite card was constructed as a mean shown in Fig. 5.

29 In developing the temperature entropy diagram the composite card Fig. 3 was redrawn, eliminating the clearance volume of steam.

30 The entropy diagram Fig. 8 shows in a graphical manner the heat transferred from the expansion side to the feed heating side of the diagram and the tendency of this regenerative feed heating method to produce a net diagram available for work approximating the rectangle of maximum efficiency.

31 To avoid the confusion of many superimposed areas, that portion of the diagram representing the heat used in the reheater line has been moved to the right a distance equal to its width. The small figures surrounding the areas representing heat transferred to work correspond to those on the pressure-volume diagram, Fig. 3.

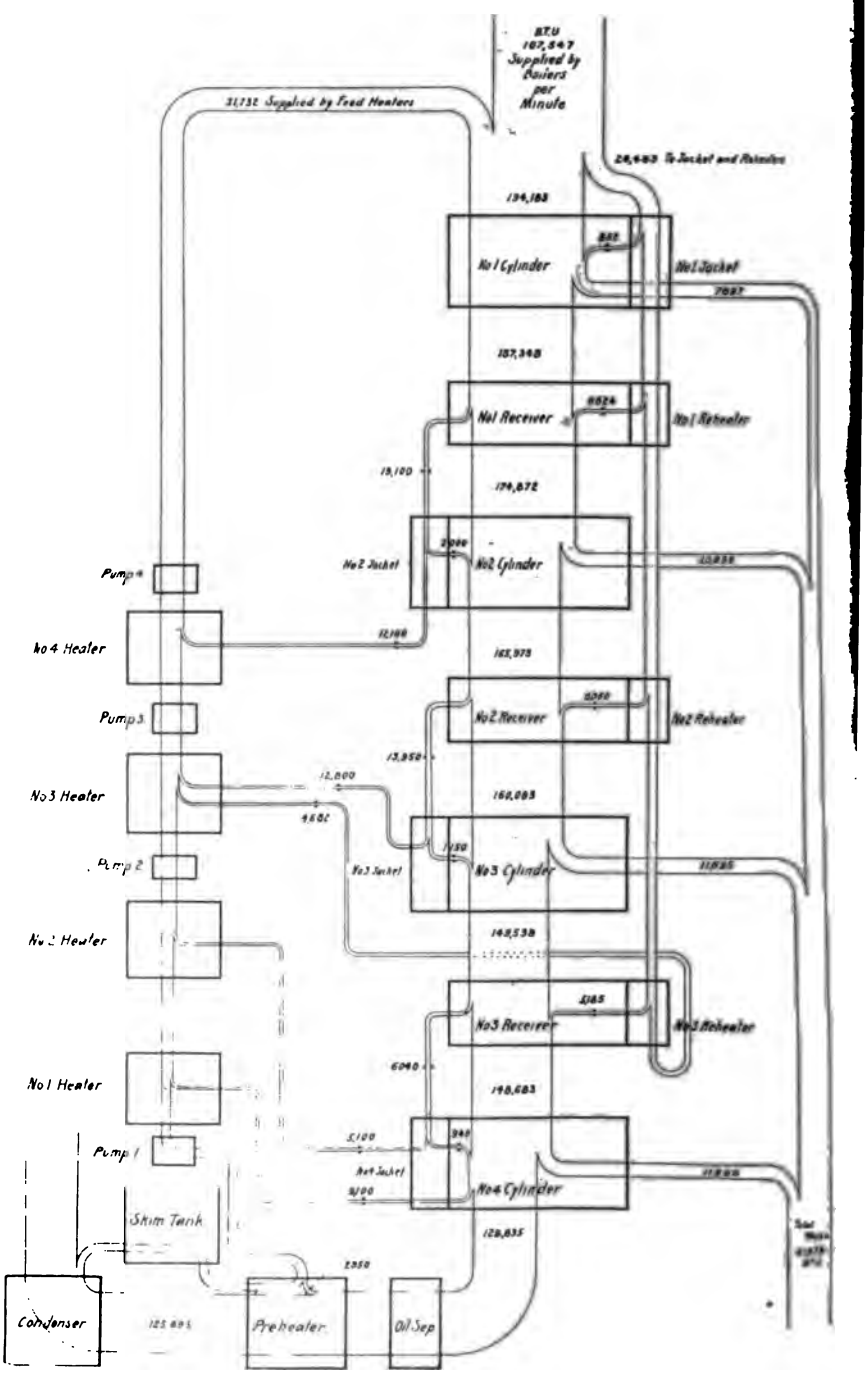


FIG. 2 DIAGRAMMATIC REPRESENTATION OF FLOW OF HEAT THROUGH THE ENGINE (APPROXIMATE DISTRIBUTION)

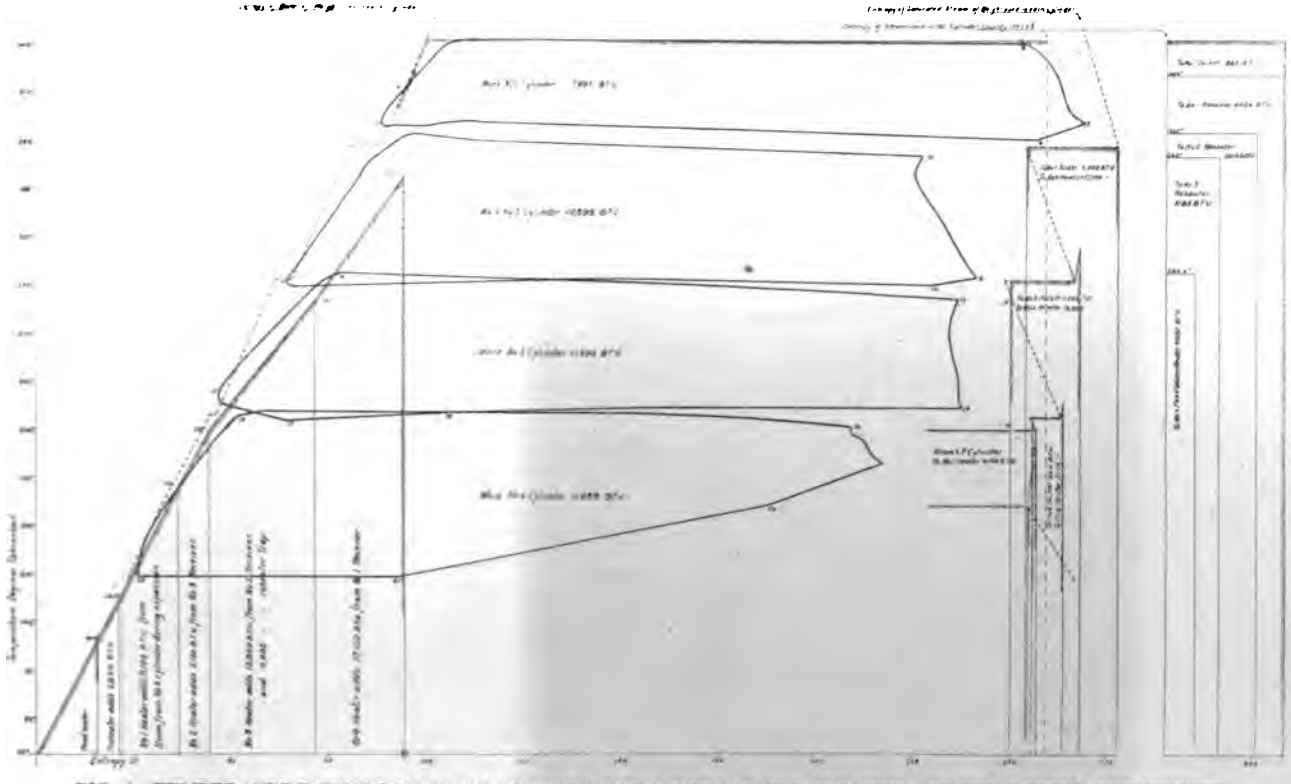


FIG. 8 TEMPERATURE ENTROPY DIAGRAM WITH APPROXIMATE DISTRIBUTION OF HEAT USED PER MINUTE,
ENGINE QUADRUPLE EXPANSION CYLINDERS 14.", 22", 38", 54" x 48" STEAM PRESSURE 256.8 ABS. 56,945 F. P M.

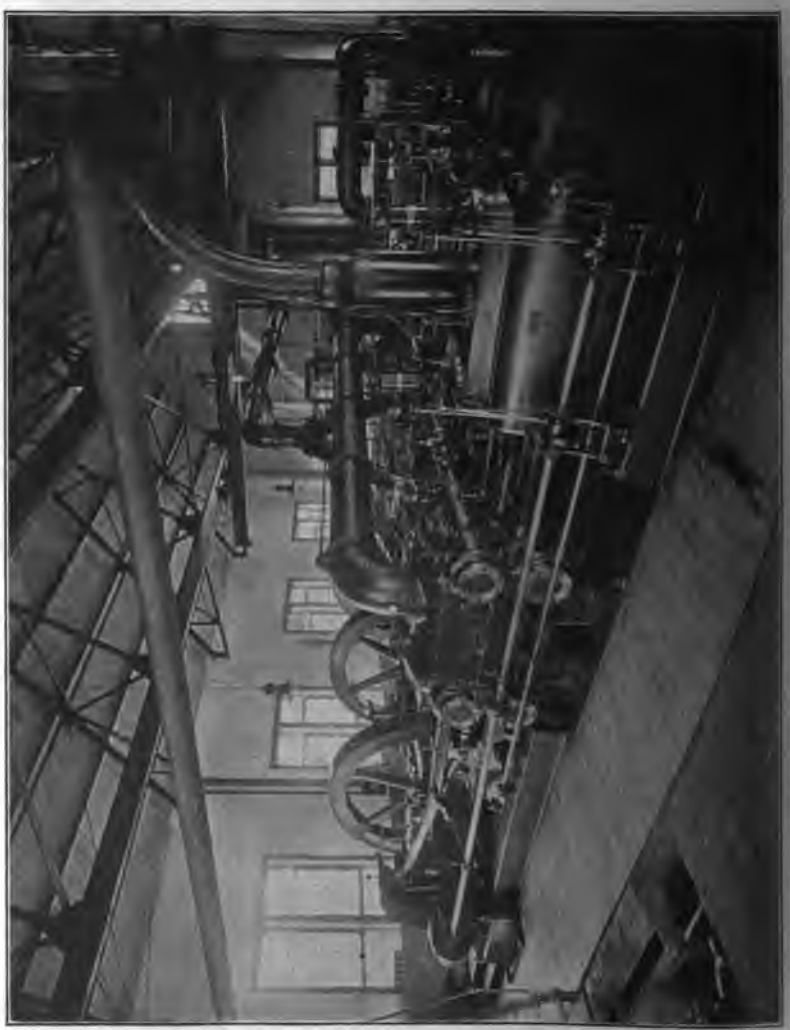


FIG. 9. SCHOOLING QUADRUPLE EXPANSION TWO-STAGE AIR COMPRESSOR AT CHAMPION MINE, PAINESDALE, MICH.

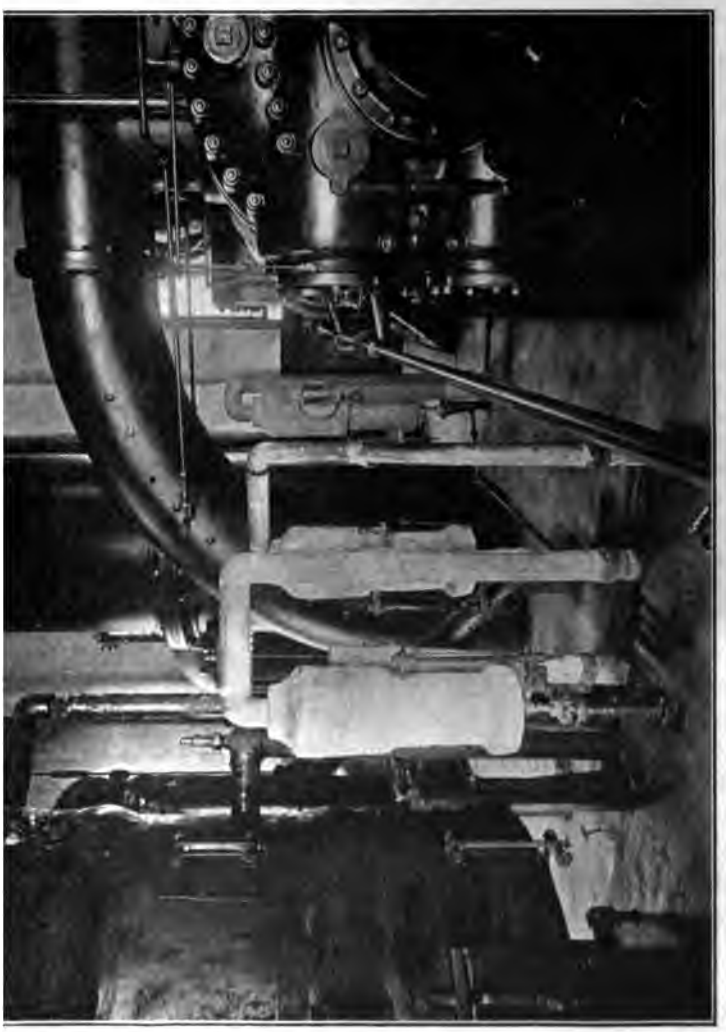


FIG. 10 FEED WATER HEATERS (ON THE LEFT) AND SEPARATING CALORIMETERS USED IN DETERMINING QUALITY OF WET STEAM USED FOR FEED HEATING

RESULTS FROM THE AIR COMPRESSING CYLINDERS

32 The air compressing is accomplished in two low pressure and two high pressure cylinders, each double acting. The four cards showing the performance of the same function were superimposed as in Fig. 7 and a composite was drawn representing the mean condition shown in Fig. 6.

33 The volumetric efficiency 98.43% and would require a speed of 77.3 r. p. m. to deliver the re ed 9000 cu. ft. of air per minute. The actual h. p. shown by the cards is 883.2 h. p. while the same weight of air compressed isothl lly would require but 731.3 h. p. showing an efficiency of the two stage compression compared with isothermal of 82.8%.

34 The temperatures of air and jacket water were as follows:

	Low pressure.		High pressure.	
Cylinder	4	1	2	3
Temperature of air entering	31	31	53.2	52.8
Temperature of air leaving	188.2	183.7	224.6	227.0
Temperature difference	157.2	152.7	171.4	174.2
Temperature of water entering jacket	42.8	58.2	73.0	82.8
Temperature of water leaving jacket	58.2	73.0	82.8	96.4
Temperature difference	15.4	14.8	9.8	13.6

35 The water was supplied to the several jackets in series through a shunt circuit from a line supplying water to the intercooler.

DISCUSSION

MR. GEO. H. BARRUS. The summary of data and results is presented in accordance with the general form adopted in the Report of the Standardization Committee of the Society given on pp. 762–767 of Vol. XXIV of the Transactions, but it is noticeable that this summary omits all data under the subject of "Indicator Diagrams" given on p. 766 of the standard table. It also omits copies of the original diagrams called for on p. 769.

2 The heat consumption given; viz, 10,157 B.t.u., equivalent to 1.016 pounds of "standard coal" per i.h.p. per hour, is based on the quantity of dry steam passing to the engine through the throttle valve. The weight of dry steam is found by deducting from the total water consumption the moisture shown by the calorimeter at the throttle valve, which is stated to be 5.74 per cent.

3 The percentage of moisture given is much greater than good practice warrants. This being the case, it would be interesting if the

author would advance some reason for it. Was it due to some fault of the boilers, or, perchance, did the calorimeter give erroneous indications? In a test like this, where the results are claimed to establish a new record, the reliability of all the data should be carefully substantiated.

4 If the calorimeter gave an erroneous indication of the moisture, and the percentage were in reality no more than usual, then the heat consumed would be four to five per cent greater, and we should have the "standard coal" increased to about 1.06 pounds per i.h.p., per hour.

5 The special interest which this high engine performance has to engineers is the one relating to the advantages of the system, in point of economy, over the practice with which we are all familar. It may be doubted whether the record proves that the distinctive features of the engine, viz., the system of abstracting heat from the cylinders for warming the feed water, are so advantageous as at first sight appears. This statement is based upon the results of tests which have been conducted by myself on steam plants embodying the ordinary system, and one instance may be cited.

6 In a plant consisting of a 650 h. p. cross-compound engine, having cylinders with a ratio volume of 7 to 1, taking steam from vertical boilers at 150 pounds pressure fitted with an economizer, the actual coal consumption for all purposes was 1.18 pounds per i.h.p., per hour. With this result as a basis, it is easy to calculate what the consumption would have been with a pressure of 250 pounds, assuming that a third cylinder were introduced using steam at 250 pounds pressure, and exhausting into the h.p. cylinder of the engine at 150 pounds. It is a conservative estimate if we assume that such a cylinder would add one-third to the power developed, and do this without increasing the consumption of steam. In other words, it would reduce the coal consumption 25 per cent, and bring it down, in the instance cited, to about 0.9 per cent of a pound. per i.h.p. per hour. This is 11 5 per cent less than the weight of "standard coal" given in the paper, and 14 per cent less than the 1.16 pounds which may be the true performance of this engine, as surmised, and a still greater percentage less than the actual amount of "standard coal" based on the heat units leaving the boiler, rather than on the heat units entering the engine, which, of course, is the basis of the real expenditure.

7 It would seem from the above calculation that a triple expansion engine can readily do as good work, and probably somewhat better work than the engine described in the paper, and no one can question the practical superiority of the triple engine in the matter

of simplicity. The multitude of heaters, pumps, etc., which form so necessary a part of the equipment of the quadruple engine described makes the engine decidedly lacking in that most desirable feature of steam machinery.

8 It is important to call attention to another matter. It would have been instructive if the records of the test had been supplemented by one made on the whole plant, embracing boilers and economizer, as well as the engine, so as to determine the actual coal consumption with this system. Such a test would have shown what benefit, if any, was derived from the economizer—an important apparatus with which the boilers were fitted. The probability is that the economizer was, in this case, of little use, for it could not have added much to the temperature of the feed water when the water was already heated before leaving the engine to 335 degrees. The question then arises, what useful object was attained by heating the feed water with steam derived from the engine, with its accompanying loss of power, when there was an economizer in the boilers which would have done the same heating with the waste gases? It is quite probable that, if a test had been made with two, or even three, of the heaters dropped off, little difference would have been found in the total coal consumption. It seems, therefore, that the system has no marked advantage when carried to the extreme limits indicated in this paper.

9 If we consider the steam engine as an apparatus for converting coal into power for commercial uses, it is certainly a wrong principle to take heat out of the steam in its passage through the various stages of the engine, and deprive the engine of that much power, when practically the same effect could be produced by utilizing the heat of the waste gases of the boiler without that loss of power.

PROF. R. C. CARPENTER The engine described in this test is similar to that used at the Wildwood station which I tested in 1900 and which was described in a paper before the Society by Dr. Thurston. The test shows that the engine is a distinct improvement over the one at the Wildwood station in its efficiency of operation. The engine of the Wildwood station was, I believe, the most economical on the basis of heat units supplied of any pumping engine which at that time had been tested. The test made by Professor Hood serves to indicate a distinct improvement in engine construction made by the Nordberg Mfg. Co. during the last six years. Both these engines were designed by Mr. Bruno Nordberg whom I consider one of the greatest engineers of this or any other age. His remarkable work has not been confined to the

field of steam engines but has also covered with the same degree of success in the air compressing and the mine hoisting machinery fields.

2 The paper covers very fully the construction of the engine and the details and results of the test. It gives, however, little or no information as to the construction and operation of the air compressor which the engine drove, and which I feel certain would have been of great interest to the Society if it had been described in detail.

MR. W. L. SAUNDERS It is proper to call attention to the fact that the paper before the Society is to be regarded as a steam engine paper and not as dealing with the ultimate efficiencies of the unit as an air compressor. How completely the air compressor is ignored may be inferred from the fact that nowhere in the paper are we told what weight or volume of air was compressed and delivered per pound of steam consumed.

2 In the ten hour run the pressure only varied two pounds and the speeds had a uniformity not consistent with common practice. We have to assume that to maintain the approximately constant load as reported the air was at times blown off or wasted.

3 It will be noted that for this quadruple expansion engine the consumption of dry steam per i.h.p. hour (p. 714) is 11.23 pounds. There is a report by Mr. Geo. H. Barrus and Mr. Geo. I. Rockwood of a test of a Cooper Corliss two cylinder compound engine at Atlantic Mills, Providence, in which the steam consumption was 11.22 pounds. This is the same type of engine often used on Ingersoll Rand Corliss air compressors. So far as steam consumption is concerned no gain has apparently been achieved by the Nordberg quadruple expansion engine over the Cooper two-cylinder engine.

4 A coal test of the Cooper engine was made by Mr. Barrus showing a result of 1.229 pounds per i.h.p. hour. This includes the operation of the steam driven auxiliaries, which would under the best conditions greatly exceed the consumption of the Nordberg engine-driven auxiliaries. The amount of steam used by the air pump, including leakage of the plant, by actual test, amounted to 20 per cent of the whole, while the Nordberg auxiliaries required only a little over one per cent of the horse power of the engine The air pump pistons in the Cooper case were in such bad shape that the loss due to this cause alone was estimated by Mr. Barrus at 3 to 4 per cent of the total coal consumption.

5 No actual coal test was made in the Nordberg case, so far as we

know; the coal consumption of 1.016 pounds per i.h.p. hour is based upon an assumed calorific value for the fuel and an assumed boiler efficiency.

6 The Cooper test is an actual commercial result, achieved with 175 pounds steam pressure as against 250 in the Nordberg, and also under very disadvantageous conditions so far as auxiliaries are concerned. Allowing for these conditions, we think the Cooper performance at least equal to the Nordberg.

7 Alluding to the air end, the compression line of each card at the very beginning of the stroke is quite perceptibly above the atmosphere line. Now, we understand that in filling the air cylinder the air is not pulled in but is pushed in by the pressure behind it, and that to cause the air to flow into the cylinder there must be some excess of pressure outside the cylinder or some deficiency of pressure within it. If the four cards from the two ends of the two air cylinders all showed the pressure to be higher in the cylinder than outside of it before compression began, the phenomenon is so remarkable as to require indisputable evidence to confirm it.

8 In paragraph 34, the volumetric efficiency of the air compressor is stated as 98.43 per cent, but it does not appear how this was computed and what has just been said may explain this extraordinary result, for, referring again to Fig. 7, the net clearance of the low pressure or intake cylinder is 2.61 per cent. This clearance is of course filled at the end of the stroke with air at the delivery pressure for that cylinder, 34.26 pounds, absolute, which compared with the intake or free air pressure of 13.96 pounds shows 2.45 compressions and the free air clearance value is then 6.39 per cent instead of the 1.57 per cent required to give the stated efficiency of 98.43 per cent and this difference would of course affect the other results given. If the intake was really above atmosphere that might affect the clearance value, but if so we should have some detailed explanation of it.

9 This attempt to advance the art of steam engineering is to be commended, and the processes of regenerative feed water heating are most interesting; but here we have a quadruple expansion engine of complex design with the attendant difficulties of very high pressure steam, refined condensing and other apparatus to promote net efficiencies. and yet the results secured, under conditions carefully adjusted for test purposes, do not show any economy in the steam consumed in the engine over those secured from the simplest form of two-cylinder Corliss compounds of about the same horse power but under commercial conditions of steam pressure, etc. It is open to grave question whether it is advisable to use reheaters, for feed water heating while

the flue gases are allowed to escape at high temperatures unutilized by economizers or otherwise. It would seem that most mine operators will continue to prefer the simpler type of machine capable of giving quite as good net results and within the abilities of the ordinary class of engineers.

MR. F. V. HENSHAW As affecting commercial results, new economies in the boiler plant look to me more possible of realization than equivalent economies to be derived from further improvements in engine design. It seems to be characteristic of the attitude of many mechanical engineers to devote much time to questions relating to engine efficiency while rather neglecting those relating to the efficiency of the rest of the plant, though the efficiency of the engine itself appears to be much nearer to the attainable ideal than is the case with furnaces and boilers. It appears to me that our existing boiler plants offer most encouraging possibilities of reductions in cost of steam power.

2 In regard to separation of oil from exhaust steam I would say that, while the situation looks bad for mechanical separation, I do not think it well to be too sure of its impossibility. Incidentally, I am informed that there is a plant in Long Island City where oil is being separated under a guarantee with something like $5 penalty per drop of oil in feed water.

MR. SANFORD A. MOSS I presume that the volumetric efficiency has been computed from the distance between admission and clearance expansion points on the indicator card. As is well known, volumetric efficiency computed on such a basis ignores heating of the air at the beginning of compression, and piston and valve leakage. There are many causes which may contribute to make the temperature of the air at the beginning of compression much higher than the temperature of the air in the suction pipe. It is, of course, evident that piston and valve leakage may also exist to a considerable degree and not be noticeable. Hence in spite of the fact that it is the custom of years to measure volumetric efficiency according to the method used by the author, there is no certainty that the method is at all correct. The only reliable method would be to actually measure the quantity of air by use of orifices, Pitot tubes, Venturi meters, or some similar method, as discussed in Mr. Coleman's paper, "The Flow of the Fluids in a Venturi Tube," or in "The American Machinist," Sept. 20 and 27, 1906.

2 I have had some slight experience in actual measurement of

volumetric efficiency and have found enormous discrepancies as compared with indicator card volumetric efficiency, principally owing to piston leakage. Personally, I am of the opinion that the average reciprocating compressor loses a surprisingly large amount of air in this way. I know of no published tests of a reciprocating compressor in which the quantity of air has been actually measured. Possibly some members have some information as to this point. A discussion of it would certainly be important.

3 Measurements of quantities of air by use of orifices, Venturi meters, Pitot tubes, etc., are often held in bad repute. There is no reason for this, however, and results to any required degree of accuracy may be readily obtained.

4 Possibly one reason for the poor opinion commonly held regarding such measurements is because of the great difference between quantities of air measured by such means and actual piston displacement. If such differences are found, they are due to inefficiency of compressor, however, and not to errors in the quantity measurement.

MR. W. Y. LEWIS It is to be regretted that the paper treats only of thermodynamics, because as everything in engineering is a question of dollars and cents, it would have been of much more valuable interest if details of costs including interest and depreciation per undivided horse power hour had been given. The author states that owing to the high cost of fuel, managers in the district have been led to install the highly efficient plant described, but the records given are not sufficient to enable one to judge whether or not the expenditure is justified. One is bound to ask at what expense this result was attained, over and above the necessary capital outlay for a more ordinary plant using superheated steam, and then make comparison to see if the saving in operating cost would be enough to warrant the increased outlay, and cover the many practical disadvantages arising from the use of such a high boiler pressure and the running of such a very complicated plant.

2 It seems to me a better all round result might have been attained if the engine had been compound, with a total of four cylinders instead of quadruple with eight cylinders. In the matter of mechanical efficiency there would surely be an improvement. Some years ago Messrs. Hick-Hargreaves of Bolton, England, made very thorough investigation as to the relative value of compound and triple engines from the friction point of view, and the following is an example of the result they invariably found. A set of 1500 horse power mill engines of the two cylinder compound type showed a loss of

friction of 5.85 per cent while a set of 1600 horse power three cylinder triple expansion engines showed a loss of 8.8 per cent. In this case a steam consumption of 12 pounds per horse power hour in the compound would be equally as efficient as 11.62 pounds in the triple, as each would require 12.74 pounds per brake horse power hour. The inference to be drawn from this is that a compound design would have been superior to the quadruple set forth by the author, especially as there are the air cylinders to be considered in addition to the steam.

3 Ten years ago there was much discussion among English mill engine builders as to the extent to which steam pressure might be advantageously raised with the consequent adoption of multiple cylinders. A number of triple and a few quadruple engines were put down, but for the last seven or eight years there has prevailed an increasing tendency toward compound engines working at 150 to 160 pounds, even for 1800 and 2000 horse power capacities, as experience has shown that, while they have great advantages in point of simplicity and reliability, they can compete very closely in thermal efficiency, being actually the least expensive and most satisfactory type of engine to use.

4 Superheating is of course being very generally adopted with the certainty of reducing losses caused by cylinder condensation, the reduction of which was the one excuse for multiplying the stages of expansion. It is surprising to me that the builders of the engine described did not take this line instead of the troublesome high boiler pressure, and the rather cumbersome total of eight cylinders. Surely it is the marine engine, where the usual valve gear employed unfortunately allows of only a limited number of expansions, that alone calls for quadruple cylinders.

5 It seems to me that there is no particular virtue in four air cylinders instead of two, anyhow it does not account for the remarkably high volumetric efficiency given as 98 per cent. This surely must be an error in view of the percentage clearances given, from which I should think the volumetric efficiency would prove to be nearer 90 per cent. Inspection of the air cards indicates other doubtful points, all tending to upset the figures given for the efficiency compared with isothermal compression. Special tests indicating such wonderful efficiencies as are given in the paper are always very doubtful.

6 Referring to the auxiliaries, I certainly do not like the arrangement of operating eleven pumps by one single crank, as any serious defect in any one of them might put the whole engine out of business—and the layout of all these important items under the floor, probably in a cramped space, doubtless leaves much to be desired. The horse

power indicated for the auxiliaries appears to be extremely small, and it is to be regretted that the power absorbed by them in the indicated horse power divided into the steam consumption was included, as it is not general to do this in testing power house plants where the auxiliaries are more properly independently driven. I would like to point out that according to the result of steam consumption per indicated horse power given, the horse power of auxiliaries was delivered at 25 per cent thermal efficiency, whereas if they had been separately driven by independent steam engines exhausting into open type feed water heaters, their thermal efficiency would have been about 80 per cent. Mr. Stott in his recent paper before the American Society of Electrical Engineers on the 59th St. Power Station of the New York Interborough Co. elucidated this point and I would again call attention to it as it is not generally recognized, moreover, it is a very strong argument against the use of electric motors for driving auxiliaries.

7 Some information about the boiler difficulties met with above 250 pounds pressure would be interesting. I note the boilers were fed from the hot well and that some kind of oil separators were used—a description of which would be desirable. There seems to be a general impression that, if oil be admitted to water tube boilers, burnt out tubes would soon result. I may be excused for digressing from the subject of this paper in stating my own experience on this point in the hope that it may prove useful to those who are inclined to use jet condensers in fear of boiler troubles arising from the use of hot well water provided by surface condensers. Pure mineral cylinder oil does no harm to boiler tubes, even if quite a considerable quantity gets in with the feed water, provided there is practically no lime present at the same time. If a compounded cylinder oil has to be used on account of wet steam supply to cylinders, then great care must be taken to extract it, otherwise its 10 per cent animal fat will cause it to stick to the tubes and cause burnouts. I have yet to be convinced that oil can be successfully extracted by any straight mechanical means. A combined chemical mechanical plant is necessary and the only apparatus I have confidence in after some fourteen years experience in this problem is the one employing alumina ferrie, which turns the saponified oil into an insoluble soap then held in fine suspension by the water from which it is easily extracted by a sand filter. I have used this arrangement with success in three large power plants and would be happy to furnish any further information members may desire.

8 I think it regrettable that engine builders do not pay more attention to the balancing problem, which is of considerable impor-

tance in the four crank engine described, though presumably it has been overlooked. Apparently, there are large unbalanced forces and couples having their own free will on the bearings and foundations of this engine, and I feel sure the judicious application of Professor Dalby's clear vector and semigraphical method of solving the problem would be attended by gratifying results.

9 Professor Hood has prepared a very interesting, if not altogether practical study in thermodynamics, and while the builders of the engine are to be congratulated on the results said to have been attained, I feel sure that if in line with other builders, they would devote their attention to the more simple and practical compound-engine compressor using superheated steam and having independent auxiliaries, they would be doing the engineering world at large, and particularly those who are often in the market, a far greater service than by specializing in such extremes as the paper indicates.

THE AUTHOR The main concern of this reply will be to substantiate the results of the test where called in question and to supplement some of the too brief explanations of the paper. Attention will also be called to what seems a wrong interpretation or a misuse of the results in order to make more clear the unique performance of this engine.

2 Mr. Barrus calls attention to the large amount of moisture in the steam, and in preparing for the test this was a surprise and was carefully investigated. It was recognized that much depended on the results of the calorimeter, and in the year preceding the test several measurements of steam quality were made with different sampling tubes, different calorimeters, and from two places in the steam pipe. During the test the sample was drawn through a perforated tube of the form recommended by Professor Carpenter and placed where for some five feet the steam had been flowing in a vertical pipe giving reasonably parallel stream lines. The position of the sampling tube seemed favorable for a fair sample, a Carpenter throttling calorimeter heavily covered with magnesia covering, was used, and the "Green" thermometer stem well protected. All of the several tests with other calorimeters and tubes led to the same conclusion of very wet steam. That the steam was of variable quality and wet was also evident to observers without instruments, as when moisture was excessive the steam pressures in the reheaters would vary and valve stems and packing show wet, so that from the very considerable amount of evidence gathered on this point I feel that "the reliability of these data has been carefully substantiated," and that there is no

need to consider the standard coal increased to 1.16 as Mr. Barrus thinks possible.

3 If the author advanced a reason for the high moisture content of the steam passing a good separator, it would be along the line of calling attention to the fact that the carrying power of the more dense steam is very much greater at 250 pounds than at 150 pounds, and that a separator or a dry pipe which may work well at the lower pressure may have reasons for failing when the carrying power of the fluid at equal velocity is greatly increased. I know of no proof of this proposition but experience with pressures above 150 pounds is limited. Mr. Barrus is in error in stating that "the heat consumption . . . . equivalent to 1.016 pounds of standard coal per indicated horse power is based on the quantity of dry steam passing to the engine through the throttle valve." It is not based on the dry steam fed to the engine but on the heat content of the wet steam, the engine being charged with the heat contained in the 5.74 per cent of moisture carried with the steam. Mr. Barrus also makes a comparison between results which he thinks he could obtain from a triple expansion engine with the actual results shown by this test.

4 The object of the paper was not to argue the relative merits of multiple expansion engines, but to state that a duty had actually been obtained which was considerably higher than had ever before been reached by any steam engine. However, I am of the opinion that Mr. Barrus has made a serious error in assuming, as a basis of calculation, that by raising steam pressures from 150 to 250 pounds and adding a third cylinder to a compound engine "that such cylinder would add one-third to the power developed without increasing the consumption of steam." If this were possible, there would be many more advocates of such high pressures for, as a matter of fact, none of the anticipated difficulties have been experienced in handling, as a commercial proposition, steam at 250 pounds pressure in this plant the engine of which is under discussion.

5 Engines which are equally effective in changing heat into work will do work in proportion to the theoretical possibility of the heat cycle they have to use. With steam at 150 pounds pressure this theoretical possibility is the return of 26.3 per cent of the heat used in the form of work and using 8.8 pounds of steam per horse power per hour. Raising the pressure to 250 pounds changes these figures to 28.5 per cent and to 8.03 pounds of steam. The high pressure steam therefore is able to yield 2.2 per cent more of its heat into work, or a gain of about 8.1 per cent, and would do this with 0.77 of a pound

less of steam. Using equal weights of steam (which is not equal heat or coal quantities) the gain would be 9.5 per cent.

6 Neither of these figures leads one to expect 33 per cent more work from the high pressure steam, nor are there practical considerations which will greatly modify this conclusion. The expansion of steam from 250 pounds to 150 pounds is not sufficient to yield one-third of the work to be obtained in expanding from 150 pounds to the usual terminal pressure of a condensing engine, and I therefore believe that the computations based on such an assumption are very far from conservative and are impossible.

7 The record which is cited for a cross compound engine is itself remarkable, and had the regenerative feed water system been applied to this engine together with the high pressure and added cylinder, a yet more remarkable result would have been obtained.

8 It is not apparent, however, that the low coal consumption of 1.18 pounds, which Mr. Barrus reports, was obtained in a manner comparable with "standard coal" assumptions. It is quite likely that in so good a plant test, the combined boiler and economizer, together with coal of high heat content yielded to the steam much more than the conventional 10,000 B. t. u. figured for the other engine, and the two figures are therefore not comparable. In the absence of a plant test of the quadruple engine, the heat furnished by the boiler per indicated horse power for the two engines are the only comparable items and this Mr. Barrus does not give for the compound engine. For the quadruple engine this is given as 169.29 B. t. u. per minute per indicated horse power or 189.7 B. t. u. per horse power of useful work delivered.

9 That the several heaters, etc., required in the feed heating system have the appearance of complication there can be no doubt, but the complication is more apparent than real. The added heaters and pumps have proved to be not so complicated as the economizer, and familiarity has removed its appearance of complication. In actual running the heaters are automatic and in the two years' use have required less attention than the economizer.

10 The suggestion to heat the feed water to the high temperature attained by using an economizer instead of the several heaters is a most natural one and looks promising until one begins to figure on the actual conditions. If 10,000 B. t. u. per pound of coal are put into the steam and the engine uses 852 B. t. u. from each pound of steam, then the boiler must have handled 11.75 pounds of feed water per pound of coal. The flue temperatures at this plant are about 475 degrees which is much lower than is assumed when great savings

are credited to the economizer. A[illegible]uming [illegible] pounds of gases are made per pound of coal and that gases leaving the economizer have the same temperature (T) as the heated feed water, then the heat given up by the gases would [illegible] 20 (475°–T°) 0.24 B.t.u. The gain in heat of the 11.75 pounds of feed water taken from the preheater and raised to the temperature (T°) could not exceed 11.75 (T°–114°). From this the possible temperature of feed water and gases leaving the economizer is found to be about 219 degrees. It is safe to say that such a low temperature of flue gases could not be reached, nor could the feed be [illegible]d above 200 degrees, while by the system adopted a temperature [illegible] high as 335 degrees was reached and a small further addition ma[illegible] in the economizer.

11 If the feed water had been [illegible]nt to the economizer from the preheater and raised to a possible 200 degrees, the boiler would have had to add 988.7 B. t. u., instead of the 852.3 required by the heater arrangement used.

12 It would have been necessary to have added 11,600 B. t. u. per pound of coal instead of 10,000 to be equally efficient, or to have reached a boiler efficiency of 86 per cent. Such a boiler efficiency has not been reached. In a plant showing very low heat consumption per indicated horse power and good boiler efficiency, the field for an economizer is much narrower than with the average plant. There may be several sources of relatively low grade heat about a plant, such as exhaust from independent auxiliaries, as Mr. Lewis suggests, or the gases just discussed, but the range of their availability for feed heating being "low grade" heat is considerably below the high temperatures reached by the heaters under discussion.

13 It seems therefore that with a well designed boiler plant an economizer can not alone equal the results obtained by this feed heating system. In view of these facts, Mr. Barrus makes too broad a statement in saying "that it is certainly a wrong principle to take heat out of the steam in its passage through the various stages of the engine and deprive the engine of that much power." This would be equivalent to saying that it was a wrong principle to take the work which has once been produced by adiabatic expansion of a gas and in the Carnot cycle put it back into the gas as heat in adiabatic compression. There is an exact parallel in the two cases and yet there is no principle more firmly established than that such a procedure leads to the highest thermal results. An engine using steam at 256 pounds pressure and rejecting all its heat to the condenser, usually works with a cycle returning a possible 28.4 per cent of the heat as work, and if it could use the most efficient cycle 34 per

cent is the theoretical limit. The system of taking heat out of the steam in its passage through the various stages of the engine to put into the feed water makes a cycle intermediate between the two above cases.

14 To many, such an explanation is lost, but it is easily grasped that an engine using 11.23 pounds of steam per indicated horse power and returning 30 per cent of this direct to the feed water with all of its latent heat, would use a smaller amount of heat than if all the steam had been rejected through the condenser.

15 Mr. Saunders' discussion attempts to focus attention upon the steam consumption per indicated horse power of two engines, and completely ignores the fact that the steam consumption is not a proper measure of the performance of an engine. It ought not to be necessary to point out the fact that an engine uses heat furnished by the coal, and uses steam merely as a convenient carrier for that heat. The quantity of heat used is the measure of its call upon the coal pile, and this is not proportional to the quantity of steam used, except in the case of engines using steam of the same heat content and returning feed water at the same temperature.

16 A proper measure of an engine's performance therefore is the amount of heat required to develop a horse power rather than the weight of steam carrying this heat. If one wished to illustrate this thesis, no better comparison could be made than between the engine of the paper and the engine mentioned by Mr. Saunders, a test of which is reported in the "Engineering Record" of November 8, 1902. This report of a Cooper compound engine with high cylinder ratio shows a steam consumption of 11.22 pounds, almost exactly that of the Nordberg quadruple. The Cooper engine used steam at 172.2 pounds gage pressure at a temperature of 418 degrees and rejected this from the engine at a temperature of 68 degrees. The steam was therefore superheated and contained 1221 B. t. u. per pound, returning only 36 B. t. u. to the boiler.

17 There should be charged to the engine therefore this difference of 1185 B. t. u. per pound of steam, and this heat must come ultimately from the coal. The plant had an economizer heating the feed to 182 degrees, and even allowing the economizer to be counted as a part of the engine, the boiler must still supply to each pound of steam 1071 B. t. u.

18 In the Nordberg engine using the same weight of steam per horse power the heat content of the wet steam was 1157.4 B. t. u. of which 305.1 B. t. u. was returned to the boiler, making a net charge of 852.3 B. t. u. per pound of steam used. The Nordberg engine

therefore used about 8/10 of the amount of heat, and therefore coal, used by the engine Mr. Saunders compares with it, although each used the same weight of steam per indicated horse power.

19 It is evidently misleading and incorrect to focus attention on the equality of the weight of steam used. A failure to recognize this fundamental thermodynamic principle has led Mr. Saunders to ask for the "weight or volume of air compressed and delivered per *pound of steam* consumed," which is a very misleading basis of comparison to present to a user where the conditions of steam pressure and feed water temperature are unlike. The factor of evaporation for the boiler furnishing steam to the Cooper engine would have been 1.11, while for the other plant it would be 0.883, and the same heat from the coal that would furnish 11.22 pounds of steam as used in the Cooper engine would furnish 14.1 pounds to the engine under discussion. This conclusion agrees fairly well with the coal consumption given for the two engines.

20 The coal used in the test of the Cooper engine was Pocahontas, probably of about 14,500 B. t. u. per pound. The rate of combustion was less than 10 pounds per square foot of grate per hour and flue temperature 448 degrees. The conditions were good for a boiler efficiency above 70 per cent and would therefore put more than 10,000 B. t. u. per pound into the steam or more than "standard coal." If the efficiency of the combined boiler and economizer was 76 per cent, 11,000 B. t. u. per pound would be put into the steam. Using 1.229 pounds of this high grade coal, as reported, per indicated horse power would be equal to 1.35 pounds of "standard coal" for the Cooper engine, to compare with the 1.016 pounds of "standard coal" figured for the quadruple engine or over 30 per cent more "standard coal" for equal work. From the relative quantities of heat used per indicated horse power in the two engines, we would expect 25 per cent more coal to be used by the compound and the 30 per cent above figured shows that the assumptions as to boiler efficiency are not far out of the way.

21 To answer the question as to the amount of air compressed, 6630 cubic feet of free air was compressed from 13.9 pounds to 85.3 pounds pressure by an expenditure of 167,547 B. t. u. contributed from the coal. This is equivalent to 2527 heat units per 100 cubic feet of free air compressed. A plant using heat under the conditions cited by Mr. Saunders where 1071 B. t. u. are used per pound of steam, would have to do this work on 2.35 pounds of steam to equal the above result. The usual bids for doing this work, when called for in

this form, run from 3.1 to 4 pounds of steam per 100 cubic feet of air compressed, depending on the steam pressure available.

22 Mr. Saunders also considers it remarkable that the "compression line of each air card at the very beginning of the stroke is quite perceptibly above the atmospheric line." This is true of three out of the four low pressure cards, and the cut is a careful reproduction of the cards as taken. This condition is neither uncommon nor remarkable. An investigation made in 1905 to determine the losses due to faulty valve action in air compressors taken just as they are found in daily running condition, led to the taking of indicator cards from large compressors at eight of the mines of this district. These machines were Nordberg, Ingersol, Rand, and Riedler, and of 34 cards taken from the two ends of 17 different air cylinders, ten of

FIG. 1 CARD SHOWING SURGING OF AIR PRESSURE IN PIPES LEADING AIR TO AIR COMPRESSORS

FIG. 2 CARD FROM PIPE LEADING TO PISTON INLET TAPPED NEAR END OF PISTON ROD AT EXTREME POSITION

these cards show the same condition as to raised compression line at the beginning of compression. So common an occurrence could not have escaped for so long Mr. Saunders' attention. The raised toe of the diagram may be due to three causes; retarded indicator movement, due to the elasticity of long string connections, inertia, and elasticity of air columns leading to cylinders, or leakage of discharge valves or piston. Care was taken to eliminate error due to the first cause by using piano wire and steel tape indicator connections.

23 That the inertia and elasticity of air in intake pipes may cause surging of pressure is well authenticated from many cards.

24 Fig. 1 shows a card taken from the inlet chamber *before* the inlet valves, of a 38″ x 48″ air compressor running at 66 revolutions per minute, and Fig. 2 from another of the same size, but of different make, running at 45 revolutions per minute. The direction of motion

of the piston is shown by the arrows. The scale of the indicator spring was four. This card shows the wavelike variations in pressure, and that at the termination of the inlet stroke the pressure at each end was above the atmosphere. If the resistance through inlet valves is low this raised pressure is also found in the cylinder.

25 The acceleration of the entering air will follow the same laws as the acceleration of a crosshead and piston modified by the elasticity of the air, but the tendency will be to lower the pressure at the beginning of the inlet stroke and raise it at the end.

26 It is well recognized that pumps with long suction lines may deliver a quantity of water in excess of the geometrical displacement of the piston if no means are provided to overcome the inertia effects of the suction column. The same effect is noticeable in a machine pumping air, although to a far less extent. I am not aware that this effect has been so commonly discussed in print as in the case of pump-

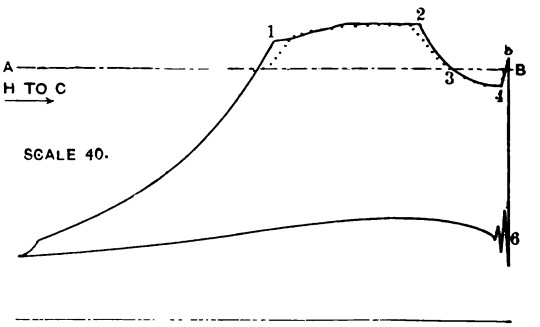


FIG. 3 CARD FROM H. P. AIR CYLINDER FROM DISCHARGE PIPE LINE AND FROM RECEIVER

ing machinery, but to show that the same inertia effects are present an illustration, Fig. 3, is given, which was taken in February, 1907, from the high pressure air cylinder of a 25″ x 39″ x 48″ Rand air compressor running at 40.1 revolutions per minute.

27 The point I wish to illustrate is that an air column started into motion may produce higher pressures at one end of that column, when retarded, than at the other end, as this is the point on which Mr. Saunders wishes "indisputable evidence." In the case of the cards which Mr. Saunders criticises, this effect is in the admission column, and I have given two cards from admission columns illustrating the fact.

28 The card from the Rand machine shows the effect more pronounced, being from the discharge column where the density of the material moved is greater. Simultaneous indicator cards were

taken from the head end of the air cylinder, giving the full line card 1 2 3 4 5 6 also from the discharge pipe line close to the cylinder, giving the dotted line closely following the line 1 2 3 4 5, and from the large air receiver placed at the end of 90 feet of 8 inch discharge pipe, giving the pressure line *A-B*. During the discharge of the air from the cylinder, a pronounced drop in pressure is noted along the line 2 3 4. That this is little effected by any question of valve opening is shown by the actual pressures at the same time in the adjacent pipe line shown in dotted lines. The pressure in the receiver *A-B* did not vary an appreciable amount, as shown by the card, so that we have the condition from 3 to 4 of air flowing from the cylinder through a pipe line against an apparently higher pressure in the receiver of over four pounds.

29 The energy of the moving air column obtained from the excessive work done in starting that column from 1 to 3 is being partly restored from 3 to 4 and is sufficient to overcome the excess of pressure in the air receiver. The elastic variation of these pressures may have such a phase with the speed of the machine as to produce quite different effects in the two ends of the same air cylinder. In compressors having restricted inlet valves these increased pressures due to inertia at the beginning of the compression stroke are not obtained in the cylinder, although they can be found in the ports leading to the valves. The foregoing evidence is such, I hope, as to remove the suspicion that a card showing a raised pressure at the moment of beginning compression is therefore remarkable.

30 The third cause of leakage, however, is responsible for most of the cases of excessive pressure at the moment of compression, and I have cards illustrating this from all types of valves which have come to my notice. In each case where leakage of the discharge valve raises the initial pressures, contributory evidence is found of the same fault of leakage in the expansion of air in the clearance volume following farther in the stroke than should be expected. Evidence of this can be found by a careful study of Fig. 7. The raised toe of the diagrams Fig. 7 is probably due to inertia and low resistance through inlet valves, and in one case to leakage.

31 The volumetric efficiency of the compressor as a whole is the mean of that found for the four cylinder ends. In Fig. 7, the mean volume of the four cards at any given pressure was taken in forming the combined composite card of Fig. 6. The volumetric efficiency was taken as $AB \div HB$ in Fig. 6. I am unable to agree with Mr. Saunders' computation of the clearance volume expansion. In the adiabatic expansion of air from 34.26 pounds to 13.96 pounds the

volume would increase 88 per cent, and 88 per cent of the clearance (2.61 per cent) is 2.3 per cent of the piston displacement instead of the 6.39 per cent which he figures. This would give a volumetric efficiency of 97.7 per cent. The well jacketed heads could be expected to reduce this volume somewhat by cooling, and I have no doubt a small leakage of some inlet valve may contribute to the lessening of the space *IIA* shown on the cards.

32 That the conventional way of measuring the quantity of air delivered by a compressor is far from satisfactory and may be quite inaccurate, is well known, and I heartily agree with the objections raised by Mr. S. A. Moss in his discussion, although I do not believe the loss is usually so large as he implies. The only excuse for continuing such a method is that, whatever it means, the results are expressed in the same terms as all other similar tests, and that there is a lack of familiarity with any more accurate method readily adapted to the conditions usually surrounding a test of a machine in the field.

33 It was the special object of this work, as stated in paragraph 2, that the test should be "under daily running conditions," and the only change from those conditions was in maintaining a uniform speed which was about the daily average speed. This was done to minimize errors in computing the power from cards, and does not introduce a refinement tending to raise the efficiency an amount sufficient to warrant Mr. Saunders' statement that the work was "under conditions carefully adjusted for test purposes." To this statement I must object, for careful investigation would show several conditions as to adjustment which could be bettered and the showing quite materially raised if the object had been a super-refined condition as implied.

34 Mr. W. Y. Lewis, Jr., in ignoring the thermodynamic facts presented, falls into the same error as Mr. Saunders in considering that the steam consumption, rather than the heat consumption, is a proper measure of the call of an engine on the coal pile. The fallacy of this has already been shown, and as to whether the saving of 20 per cent of the coal will warrant the increased capital expenditure is a matter that must be settled for each separate case and include more factors than have been considered either in the paper or in the discussion.

35 Mr. Lewis' regret that information on several subjects of interest relating to the plant was not given, must be met by the author's statement that on any test of so large an engine embodying so many interesting features, a large book might be written and it was the intention rather to write a paper, focusing attention on the actual

performance and upon the unique features of the feed water heating system and high steam pressure which together are responsible for this new high duty record. That this system is not readily grasped at present by engineers is shown by the discussion, but that a more careful study of its possibilities is warranted is shown by the high duty attained. This principle is not necessarily accompanied by several expansion cylinders, but is applicable as well to compound engines although perhaps not so readily. It would seem to be especially easy to apply this cycle to turbine engines. That the actual running of the engine as a whole, the peculiar heating system in particular, and the use of high pressure steam have been satisfactory and continuous and free from trouble is the report of the operating engineer. It is my opinion that in this plant there has been no trouble with the boilers due to oil, such troubles as have arisen being more easily explained along other lines.

36 Regarding the high volumetric efficiency, reply has already been made, and to the easy way in which Mr. Lewis would "upset the figures given for efficiency" without specific statement of any kind, no answer can or need be made. It is not apparent what evidence can be gathered from the paper or the running of the machine to warrant the reference to a balancing problem, and familiarity with the running of the machine does not suggest a lack in this respect.

37 Mr. Lewis would prefer a compound engine because of its superior mechanical efficiency, but loses sight of the fact that the ultimate result based on the delivered work, in spite of the greater number of cylinders involved, is still about 6 per cent better than the best pumping engine practice, although an air compressor must involve a greater amount of mechanism and friction. To attain this high result, recourse was had to a thermodynamic principle new in practice which involved high pressures to which the compound engine was not suited and to which the quadruple engine was peculiarly fitted for reasons, among others, of its adaptability to the working out of this principle in the heater system. For mechanical reasons the four air cylinders naturally follow the selection of four steam cylinders.

38 The assumption that the boiler pressure used is troublesome is unwarranted. A new boiler has recently been started in this plant under the high pressure with as little difficulty as could attend the cutting in of any new boiler under the more common pressures and with certainly no more trouble than is involved in superheater practice. Mr. Lewis' advice to the builders to devote their attention to "the more simple and practical compound engine," of which they

have many examples, must be coupled with the fact that the best high duty pumping engines are quite generally admitted to be triple expansion engines. The actual horse power involved is usually far below that of the compressor under discussion, and there appears no reason why a compound engine should be the best for pumping air, and a triple best for pumping water.

39 The briefness with which me of the results are presented has been criticised, and the author is quite ready to admit that in the process of boiling down what might have been a long paper he has gone too far and eliminated too much. Many points in such a test are of no value to the casual reader, but are of great interest to one looking for the way in which the matter has been handled before. The temperature-entropy diagram was introduced as it was thought to be of use only to those attempting to solve the same problem, for the form must contain more than the usual entropy diagram to show the abstracted steam and the heating device.

40 The several combined diagrams were made as follows: Cards were taken from each end of each cylinder at the same instant by electrically controlled indicators, and, therefore, represent an instantaneous condition of the use of steam. Of the twenty sets of cards, one typical set was selected which gave a horsepower close to the average and whose cards were as good as had been made. Since the two ends of a cylinder did not use steam in exactly the same way, the cards were drawn in the form of Fig. 4 showing both cards. In this redrawing, the mean effective pressure to the new scale and the mean effective pressure of the original card were compared to act as a check on the accuracy of the work. Since an entropy diagram could not be drawn from a card having such double lines, a new card, Fig. 5, was produced by taking the average pressure of the two as found at each abscissa representing piston position and checking the mean effective pressure of this combined composite card against the average of the two original cards from which it was made. The saturation curves for this diagram were drawn for the weights charged to each cylinder given in Par. 24. To eliminate the effect of the clearance steam, Fig. 3 was drawn by the method given in Sidney Reeves' "Thermodynamics of Heat Engines." From this the entropy diagram, Fig. 8, was constructed. Horizontal distances represent the entropy of the mixture used per minute and if it is borne in mind that the first intermediate cylinder does not have the same weight of steam fed through it as the high pressure cylinder, the reason for the "broken water line on the left of the diagram" is at once apparent, and also the broken dotted line to the right, which represents the

entropy of saturated steam fed through each cylinder. As the weight of steam fed to each succeeding cylinder grows less, the entropy of steam and water is less and moves these lines to the left. The chart is an entropy diagram of the four engines to the same scale, but each using a different quantity of steam, combined with a chart showing the distribution of the heat which is withdrawn between each cylinder and put into the feed water, and a chart showing the disposal of the reheater steam.

41 These later features are unusual and give the diagram an unfamiliar look. From the entropy diagram of each cylinder the steam accounted for at any point in the stroke can be determined by a simple measurement, as asked for by Mr. Barrus. In the upper work area of this diagram for the high pressure cylinder the steam is shown to be gaining heat from 2 to 3.

42 From 3 to 4 there is a loss of entropy during the terminal drop at exhaust and heat is rejected during exhaust from 4 to 5. The weight sent to the next cylinder being less, the reduced entropy of both water and steam is shown by drawing these dotted entropy lines to the left, and the area under the horizontal line just below 4 is proportional to and represents the heat sent to the next jacket and to No. 4 heater.

43 On the left of the diagram, part of this area appears as representing the last increase in temperature and entropy of the feed water. The area representing the heat sent through the first jacket and the reheaters is shown slipped to the right to avoid confusion. The horizontal width of this area represents the entropy sent to the high pressure jacket and at the temperature level shown. The area below this top horizontal line represents the total heat sent to this jacket.

44 When the steam carrying the heat enters the first reheater it is found to have dropped to a lower temperature level, as shown, and to have lost entropy and the area below this line represents the heat sent to the first reheater. The difference in the two areas, therefore, must represent heat given up to the high pressure cylinder, most of which is shown by the gain in heat in steam falling in temperature from 2 to 3 in the high pressure work diagram. Similiarly each loss of heat is shown.

45 The areas (down to an absolute zero line) representing heat lost to feed heaters, check very well with those trapezoidal areas on the left representing heat gained by the feed water as it starts at a low temperature level and has its weight, temperature, and entropy increased until it reaches a final temperature of 334.5 degrees. Had the engine developed a perfect Carnot cycle the entropy of the feed

water leaving the engine would have been shown at the intersection of the dotted entropy-of-water li and the highest temperature level. This is left for the economizer to close. How near this theoretical condition is reached is seen at a glance and it is this feature of the engine which is unique.

No. 1132

TEST OF A ROTARY PUMP

By W. B. GREGORY, NEW ORLEANS, LA.
Member of the Society

1 Four years ago a paper, entitled "Rotary Pumps," was contributed to this Society by Mr. John T. Wilkin. This paper left very little to be said concerning the details of construction of the two lobed, cycloidal pump. The largest pumps of this class have been built in response to a demand in the rice irrigation districts of Louisiana and Texas, where there are pumping plants having an aggregate capacity of 1,100,000 gallons per minute. The development of these large irrigation plants has taken place in the last ten years. The annual statement of the expenses of operation and especially of the fuel bills, has shown the plants using rotary pumps to be very economical. This is due in part to the direct connected compound condensing Corliss engines that are often used to drive the pumps, and in no small measure to the efficiency of the pumps themselves.

2 In the paper referred to above, this statement was made, "The writer has taken many indicator cards from engines operating rotary pumps and finds the combined efficiency of the pump and engine to be 80 to 84 per cent." Some engineers were skeptical in regard to the truth of this statement, as the efficiency stated is the product of two efficiencies, viz: that of the engine and that of the pump. Experience with centrifugal pumps had taught that a pump efficiency of nearly 90 per cent was too good to be true. The writer was among the doubting ones and, for this reason, gladly welcomed an opportunity, offered during the summer of 1905, to test a pumping plant using rotary pumps. The plant is located near Abbeville, La., is used to furnish water for rice irrigation, and is the property of the Abbeville Canal Company. One of the units of this plant is shown in Fig. 1.

3 The results of this test form a part of Bulletin 183, Office of Experiment Stations, U. S. Department of Agriculture, entitled "Mechanical Tests of Pumps and Pumping Plants Used for Irrigation and Drainage in Louisiana." The height through which the water

Presented at the New York Meeting (December, 1906), of The American Society of Mechanical Engineers, and forming part of Volume 28 of the Transactions.

DESCRIPTION OF THE PLANT

6 The boiler equipment of this plant consists of two water tube boilers, built by the Erie City Iron Works, each of 400 nominal horse power, having 3675 square feet of heating surface. Each boiler has two drums, 42 inches in diameter, 21 feet in length, and 180 four inch tubes, 18 feet long. A breeching, 72 inches in diameter, conducts the burned gases to a steel stack of the same diameter, resting on a brick base; the length of stack is 90 feet and the total height above the furnace is about 115 feet.

7 Steam is conducted from the boilers by separate pipes to a main which supplies the various engines. By means of a stop valve, the two halves of the plant may be separated and boiler No. 1 used to supply steam to engines No. 1 and 2, and boiler No. 2, used with engines No. 3 and 4. There are steam separators above each engine.

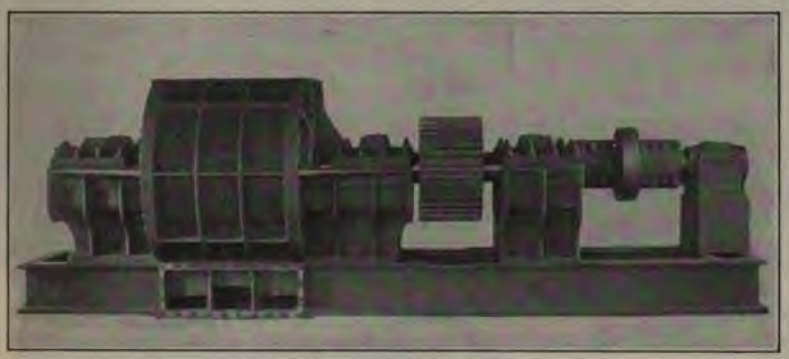


FIG. 2 ONE OF THE PUMPS OF MAIN PUMPING PLANT, NECHES CANAL CO.

8 The fuel used was crude petroleum, which was fed to the furnaces by gravity, as the storage tanks are located at a height considerably above that of the furnaces. Steam is used to atomize the oil.

9 There are four tandem compound condensing Hamilton Corliss engines, dimensions, 18 x 36 x 48 inches; piston rods $4\frac{5}{8}$ and $3\frac{1}{4}$ inches in diameter. Each engine is directly connected to a rotary pump by means of a flexible coupling. Keys of babbitt metal are used in the couplings; these keys are made strong enough to carry the load, but will shear in case a piece of wood or other obstacle gets into the pumps.

10 The pumps are two lobed, cycloidal, of 39 inches pitch diameter. The impellers are 52 inches in length and $58\frac{1}{2}$ inches in diameter; the displacement is 605 gallons per revolution. The bearings are 11 inches in diameter by 30 inches in length. The details of construction may be seen in Fig. 2 and 3. The Connersville Blower

12 Two direct acting steam pumps are used for boiler feeders, when the entire plant is in operation; they are outside packed, double-acting, having dimensions 15 x 8 x 12 inches. The usual number of double strokes is about 21 per minute.

FIG. 5 PUMPING PLANT IN PRO ESS OF ERECTION

13 There are two No. 7 Cochrane heaters; each receives the exhaust from one vacuum pump and one feed pump.

14 Two views of the plant in process of erection are given in Fig. 4 and 5; the magnitude of the plant may be gaged by means of the discharge pipes which are 48 inches in diameter. A cross-section of the plant showing the location of the engines, the suction and discharge pipes, and the connection of the latter with the steel flume, which conducts the water to the canal, is shown in Fig. 6.

DESCRIPTION OF TESTS

15 The object of the tests was to determine the various efficiencies of the plant, the mechanical efficiency of pumps and engines, and the cost of operating. Great care was used in measuring the input of energy in the form of fuel oil and the output in the form of useful water horse power.

16 On August 8, engines and pumps No. 3 and 4 were run. Steam was furnished by boiler No. 2. The stop valve in the steam

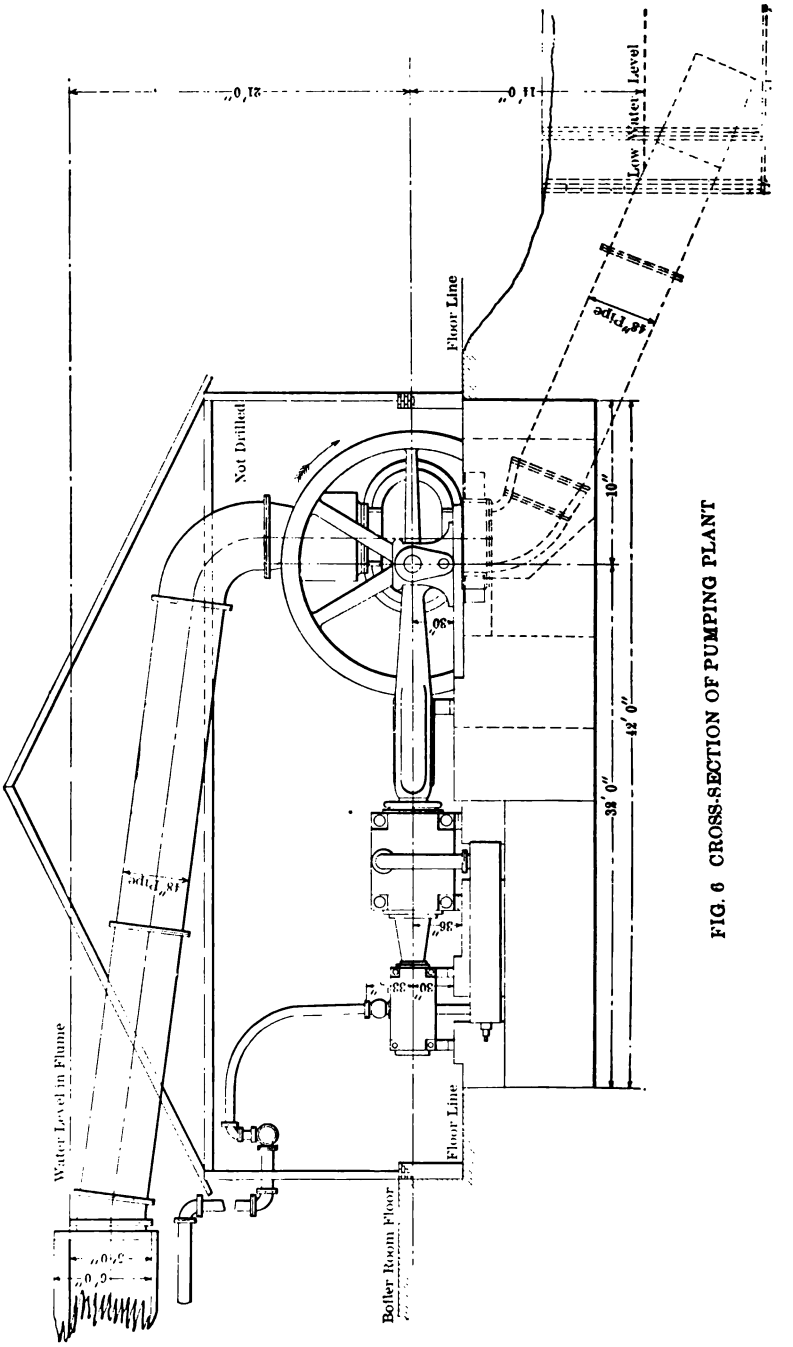


FIG. 6 CROSS-SECTION OF PUMPING PLANT

main between the two halves of the plant was closed. There was some leakage at this valve and also at the two blow-off valves of the boiler used. Leakage of air through boiler No. 1, into the breeching caused another loss.

17 A second test was run on August 9, 1906, with the entire plant in operation. During this test there was no leakage from the blow-off pipes of either boiler. The drain pipes from the steam separators were closed on both days; the other leaks from the steam main were small and no attempt was made to measure them.

18 On the first day, continuous counters on engines No. 3 and 4 were read at intervals of five minutes; readings for 15 minute intervals are given in the general log. For computing i.h.p. the revolutions were taken from the five minute interval during which the cards were taken. Indicator cards were taken every half hour.

19 The discharge from the two pumps was carefully measured in flume No. 2 by means that will be described later. The theoretic displacement of pumps and their actual discharge were compared, and the mechanical efficiency of engines and pumps determined.

20 Observations were also taken, at half hour intervals, of boiler pressure, the temperatures of feed water, calorimeter, water pumped, air, and fuel oil. A draft gage, connected to an air valve in the breeching, gave the draft in inches of water.

21 The fuel oil was carefully measured in a calibrated barrel and its specific gravity observed throughout the test by means of a hydrometer.

22 The amount of boiler feed water was measured by means of a weir.

23 On the second day when the whole plant was in operation, the total water discharged from both flumes was measured at intervals of 15 minutes; the water measurements were so made that they were repeated in each flume at half hour intervals.

24 The head was carefully measured in the same manner as on the previous day, the fuel oil was carefully measured, and the steam pressure was held exactly as on the first day. In this way, the total useful work done and the amount of fuel required to operate the entire plant were measured under conditions exactly corresponding to those of the previous day.

INSTRUMENTS USED

25 The feed water was measured only during the test of August 8. As the tests were to represent as nearly as possible the conditions of ordinary operation, it was desirable to use the heaters, the water

level in which was only about two feet above the center of the feed pump. The high temperature of the feed water made it necessary to have the water flow by gravity to the pump. The pipe connections were short and the measurement of feed water in calibrated tanks could only be accomplished by the aid of an extra pump, or by taking cold water from the flume. A trapesoidal weir, six inches in width, was introduced between the heater and pump by slight changes in the piping. The discharge from the weir was into a barrel, connected to the suction of the feed pump. The height of the water above the sill of the weir was measured by an accurate hook gage. In this way the plant was operated under normal conditions and the water measured with reasonable accuracy. The weir had been previously calibrated in the Hydraulic Laboratory of Tulane University of Louisiana, and its constant determined. It is believed that the error involved does not exceed 2 per cent and that it is probably only half that amount.

26 By this method all the water fed to the boiler was measured. The steam generated by the boilers was used by the main engines, by vacuum and feed pumps and for atomizing the fuel oil.

27 The quality of the steam was obtained by means of a throttling calorimeter in the vertical pipe coming from the boiler, a short distance above the junction of the vertical pipe with the horizontal main.

28 The conditions of the boiler test were extremely uniform; the water level changed very little, and the rate at which water was supplied to the boiler was not varied throughout the test. Steam pressure, quality of steam and the temperature of feed did not vary perceptibly.

29 The boiler pressure and the vacuum were read by means of calibrated gages. The error of the thermometer used in the calorimeter was known and the correction applied.

30 Two Crosby indicators were used on engine No. 3, and two Thompson indicators on engine No. 4. All were supplied with wheel reducing motions. Each cylinder of each engine was fitted with three way cocks: 80 lb. springs were used on the high pressure cylinders, while 20 lb. springs were used on the low. The springs were calibrated after the test and corrections applied where necessary.

31 The barrel in which fuel oil was measured was calibrated by means of an accurate spring balance.

32 Samples of the fuel oil were taken from time to time during the test, and later a careful determination of the heat value was made at the Tulane University of Louisiana. The heat units per pound were found to be 18,790; the amount of water present in the oil was 2 per cent. The oil was from the Jennings, Louisiana, field.

WATER MEASUREMENTS IN THE FLUME

33 The height through which the water was lifted was obtained by measuring down from bench marks on the suction side of the pumps to the water level in the suction flume, and again from a bench mark on the discharge side to the level of water in the discharge flume. The head was extremely constant. All linear measurements taken by means of a tape were corrected by comparison with a steel tape.

34 The discharge of pumps No. 3 and 4, is into a common flume, built of ¼ inch steel, having an inside width of 8.71 feet. The depth of water in the flume was obtained by measuring the distance from an angle iron across the top of the flume to the bottom and subtracting the distance from the angle iron to the surface of the water. The depth of the water varied little from 4.17 feet throughout the test; each time six observations were taken and averaged.

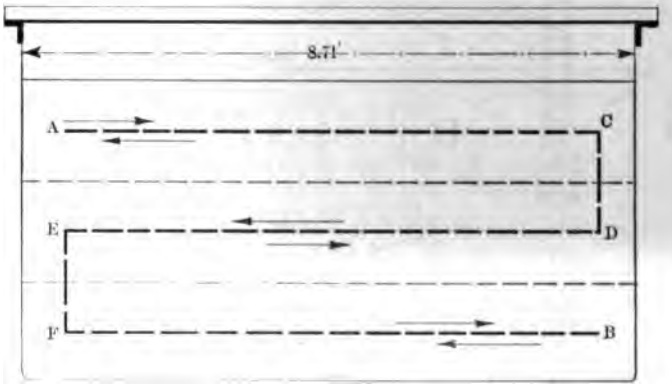


FIG. 7 CROSS-SECTION OF FLUME SHOWING METHOD OF MAKING A TRAVERSE WITH CURRENT METER

35 Two instruments were used alternately to determine the mean velocity of the water—a current meter and a Pitot tube. The current meter is a Gurley No. 31, the property of the Office of Experiment Stations, U. S. Department of Agriculture. It had not been used since it was rated and was in an excellent condition. The stop watch ordinarily used with the meter was found to be broken just as the test was started so a common watch was used throughout. The confusion of counting revolutions of the current meter by means of a buzzer and at the same time keeping accurate tally of the time without a stop watch, was accountable for the failure to get results at 6 p. m. and again at 6.30 p. m. when the operator was fatigued by several hours of hard work in a broiling sun.

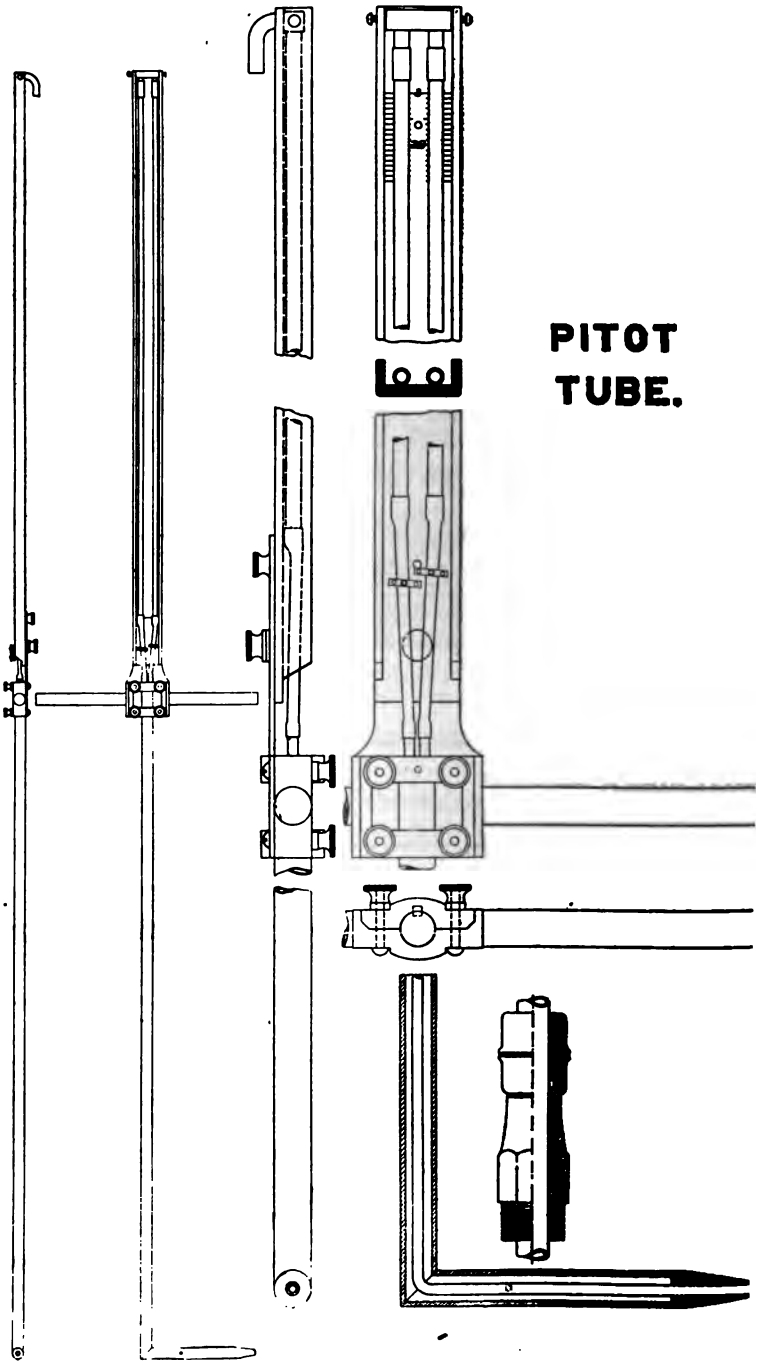


FIG. 8 PITOT TUBE

36 The method of making a traverse with the current meter is clearly shown in Fig. 7. The meter was lowered to the starting point *A* and slowly moved along the dotted path to *B* and then back again to the starting point. The movement was so slow that no correction for the component of side motion was required, as the time was usually about five minutes. Between the points *C* and *D* and also between *E* and *F* the meter was moved rapidly in order to avoid the error due to the slow velocities near the sides of the flume.

37 The Pitot tube used is shown in Fig. 8. This instrument is the property of Tulane University of Louisiana and was designed by the writer. The constant c of the instrument is unity in the formula,

$$v = c\sqrt{2gh}$$

This instrument has proved to be very accurate and reliable, and experience has shown that in both these qualities, it is the equal

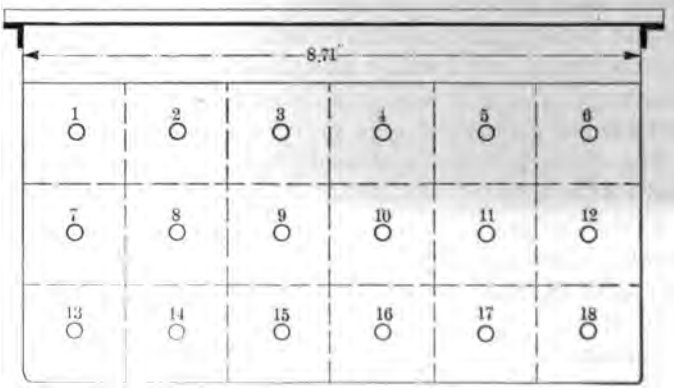


FIG. 9 CROSS-SECTION OF FLUME SHOWING POINTS WHERE VELOCITY WAS OBSERVED BY MEANS OF THE PITOT TUBE

of the current meter in open channel work where the velocity is four feet or more per second. The method of using the Pitot tube is illustrated in Fig. 9. The cross-section of the flume was divided into eighteen rectangles, approximately squares, and the point of the instrument held facing the current at the center of these rectangles; the arithmetical mean of the velocities found was used as the mean velocity of the water in the flume

ACCURACY OF WATER MEASUREMENTS

38 The general log shows the percentage difference between the discharge and the displacement of the pumps, in terms of the latter,

for separate observations; this "slip" is sometimes positive and sometimes negative. The displacement was computed from the five minute observations of the revolution counters; while small errors will occur in individual cases they will balance each other in a series of observations. The accuracy of results can therefore best be judged from average results; in this way a comparison can also be made between the results obtained by the two instruments.

39 The average of all readings taken with the current meter gives a discharge of 152.99 cubic feet per second, while the average displacement of the pump for corresponding readings averages 152.90. The average of all readings of discharge obtained by means of the Pitot tube, gives 152.79 cubic feet per second; the average displacement for corresponding readings is 152.92 The agreement in both cases is remarkable and can lead to but one conclusion, viz: that the discharge of the pumps is practicallv equal to their displacement. After making the above comparison and reaching the conclusion stated, the useful horse power for the test of August 8 was computed on the basis of displacement instead of discharge; this makes the results a little more regular and does not affect average final results. Measured discharge was, of course, used in computing the results of the test of the entire plant on August 9.

40 The writer believes these results to be as accurate as could be obtained with a weir.

41 Acknowledgment is hereby made to Mr. J. F. Taddiken, Jr., at present in the employ of the Sewerage and Water Board of New Orleans; to Mr H. P. Porter of the Connersville Blower Company; to Mr. C. O. Brookshire, chief engineer of the Neches Canal Company, and to his corps of assistants for valuable aid during the tests.

BOILER TEST, AUGUST 8, 1906

TEST OF ENTIRE PLANT, AUGUST 9, 1906

TIME	TEMPERATURES: FEED	CALORIMETER	WATER PUMPED	FUEL OIL	AIR	DRAFT GAGE	QUALITY OF STEAM	FEED WATER POUNDS	TIME	FUEL OIL POUNDS	SP. GR. OIL	BOILER PRESSURE	PLUME NUMBER	TIME OF TRAVERSE	MEAN DEPTH	VELOCITY	DISCHARGE CU. FT. PER. SEC.	INSTRUMENT USED	HEIGHT THROUGH WHICH WATER WAS LIFTED: NO. 1	NO. 2	NO. 3	NO. 4	MEAN	USEFUL WATER H. P.	FUEL OIL: TIME	POUNDS	SP. GRAVITY	TEMPERATURE
1:30	198	290	81.5	93	93	.43	99.1		1:30		9	140	2	8:00– 8:08	4.34	3.694	139.5	P. T.	31.99	31.99	31.88	31.93	31 95		7:25			
									1:45	336			1	8:15– 8:23	4.18	4.168	151.5	P T.							7:39	672	.9	88
2:00	199	290	81.5	93	94	.43	99.1	7241	2:00	672	9	140	2	8:30– 8:42	4.40	3.618	138.5	C. M.							8:01	1344		
									2:16	1008			1	8:45– 8:52	4.14	4.236	152.5	C. M.	32.09	32.09	32.06	32 0	32 06		8:20	2016	.9	90
2:30	199	290	81.5	94	94	.45	99.1	14482	2:34	1344	.9	140	2	9:00– 9:09	4.40	3.684	141.0	P. T.							8:41	2688		
													1	9:15– 9:28	4.09	4.214	150.0	P. T.							9:02	3360	.9	91
3:00	199	290	81.5	94	93	.46	99.1	21723	2:54	1680	.9	140	2	9:35– 9:43	4.38	3.585	136.5	C. M.							9:23	4032		
									3:13	2026			1	9:46– 9:54	4.08	4.180	148.4	C, M.	32.09	32.09	31.98	32.03	32.05		9:44	4694	.9	92.5
3:30	199	290	81.5	94	93	.48	99.1	28964	3:30	2352	.9	140	2	10:00–10:08	4.38	3.524	134.2	P. T.							10:04	5376		
									3:47	2688			1	10:15–10:25	4.07	4.237	150.2	P. T.							10:23	6048	.9	
4:00	199	290	81.5	93	92	.50	99.1	36205	4:06	3024	.9	140	2	10:30–10:39	4.36	3.686	139.8	C. M.										
									4:22	3360			1	10:45–10:53	4.06	4.463	157.5	P M.	32.04	32.04	31.93	31.76	31.99		10:44	6720	.898	92.5
4:30	199	290	81.5	92	88	.50	99.1	43446			.9	140	2	11:00–11:08	4.34	3.749	141.4	P. T.							11:05	7392		
									4:40	3696			1	11:15–11:23	4.05	4.403	155.3	P. T.							11:25	8064	.898	95.5
5:00	199	290	81.5	90	87	.50	99.1	50687	4:58	4032	.9	140	2	11:30–11:37	4.33	3.790	142.8	C. M,							11:47	8736		
									5:16	4368			1	11:45–11:53	4.03	4.268	150.1	C. M.	32.04	32.04	31.93	31.96	31.99		11:58	9072		
5:30	199	290	81.5	89	86	.50	99.1	57928	5:34	4704	9											Mean	32.01	C054				
									5:52	5040																		
6:00	199	290	81.5	88	85	.49	99.1	65169	6:11	5376	9																	
									6:29	5712																		
6:30	199	290	81.5	86	84	.48	99.1	72410	6:47	6048	9																	
7:00	199	290	81.5	85	81	.48	99.1	79651	7:055	6384	9																	

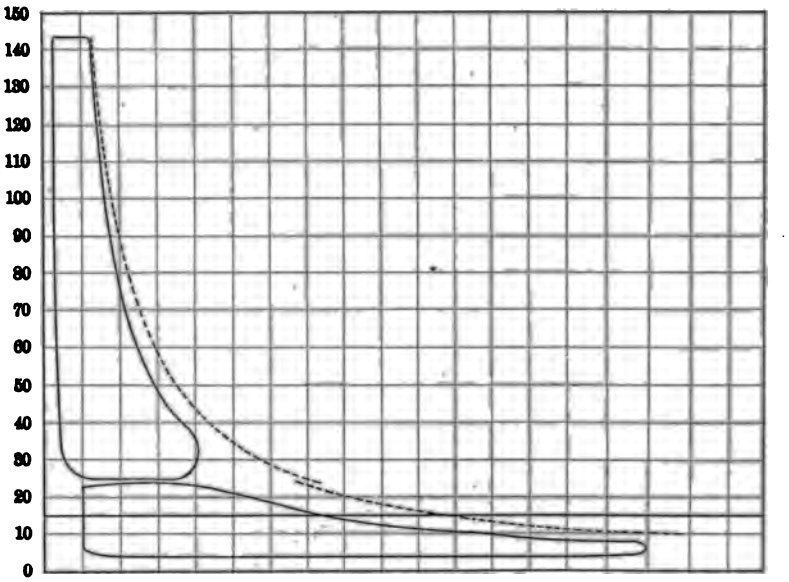


FIG. 10 COMBINED CARDS ENGINE NO. 3 HEAD END
TIME, 5:30

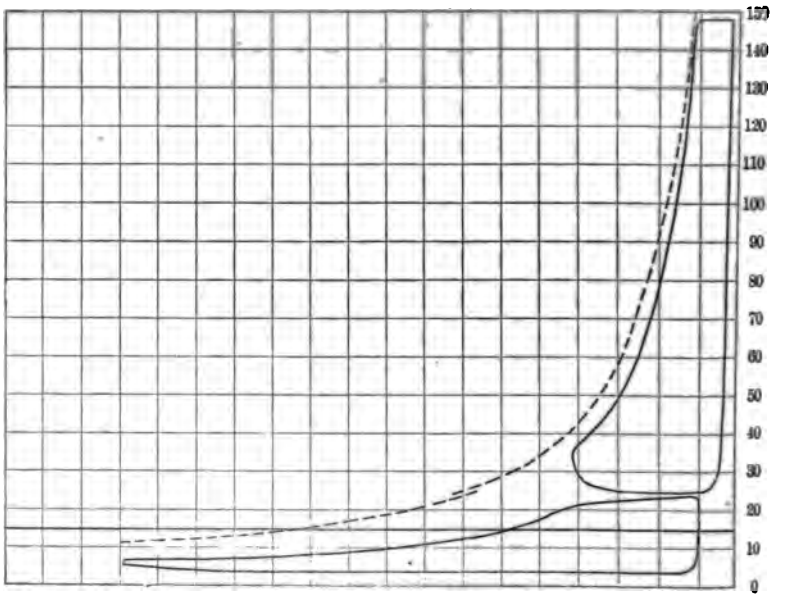


FIG. 11 COMBINED CARDS ENGINE NO. 3 CRANK END
TIME, 5:30

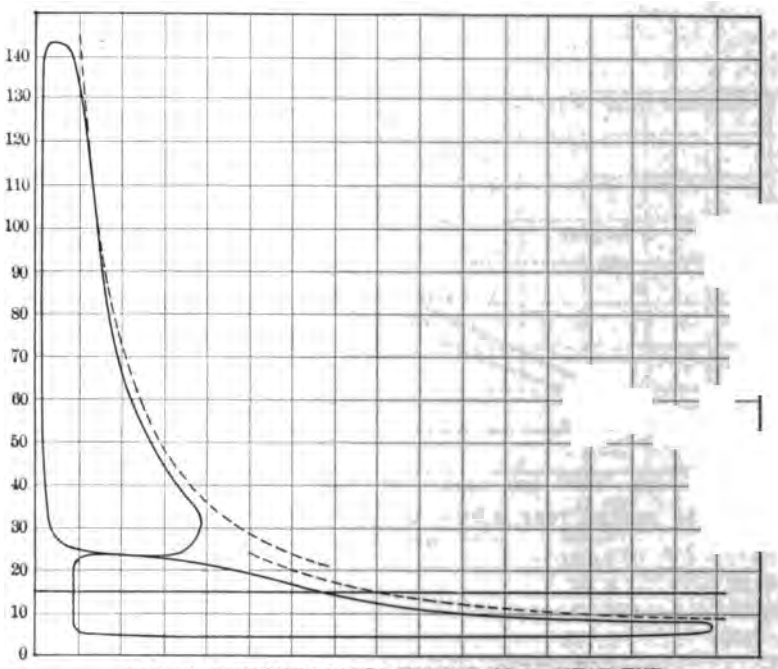


FIG. 12 COMBINED CARDS ENGINE NO. 4 HEAD END
TIME, 5:30

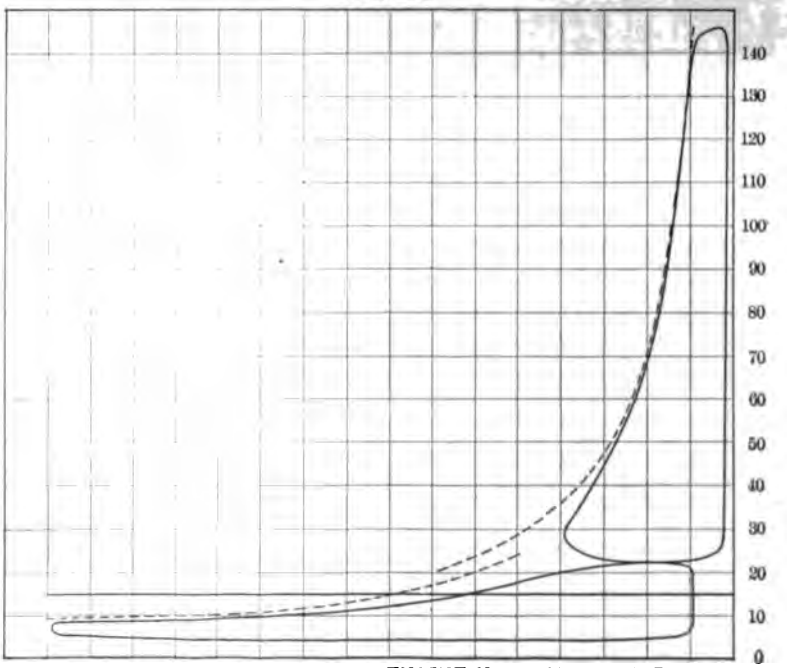


FIG. 13 COMBINED CARDS ENGINE NO. 4 CRANK END
TIME, 5:30

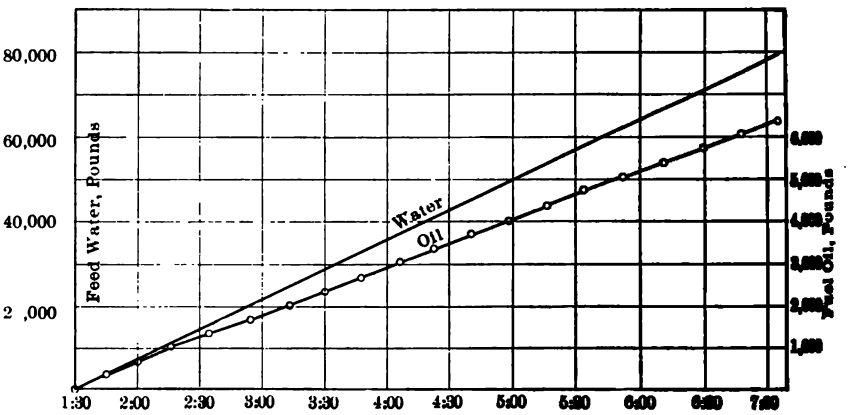


FIG. 14 BOILER TEST, MAIN PUMPING PLANT, NECHES CANAL CO.
AUGUST 8, 1906

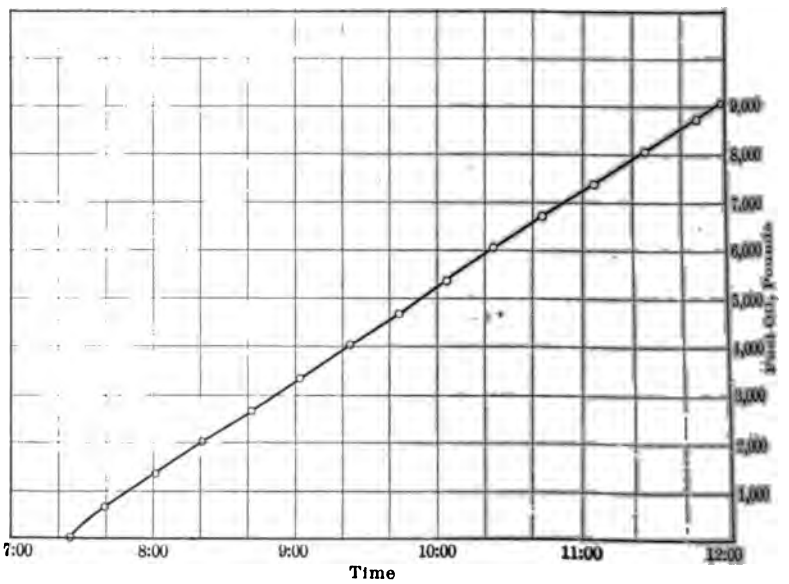


FIG. 15 MAIN PUMPING PLANT, NECHES CANAL CO.
AUGUST 9, 1906

TEST OF MAIN PUMPING PLANT, NECHES CANAL COMPANY, NEAR BEAUMONT, TEXAS

Summary of results

	August 8	August 9
Duration of test, hours	5.592	4.55
Type of engine, tandem compound condensing Corliss, dimensions, 18 x 36 x 48, number operated	2	4
Type of pumps, Connersville cycloidal rotary (operated)	2	4
Mean i h. p., No. 3	321.5	
Mean i h. p., No. 4	336.2	
	657.7	
Difference of level between suction and discharge	31.62	32.01
Cubic feet of water pumped per second (measured)	152.9	291.2
Displacement of pumps, cubic feet per second	152.7	
Temperature of water pumped, degrees F.	81.5	81.5
Weight of water per cubic foot	62.21	62.21
Useful water h. p.	547.9	1054.
Mechanical efficiency of pumps and engines, per cent	83.3	
Heater, Cochrane (open)	1 No. 7	2 No. 7
Boilers (water tube), Erie City Iron Works	1-400 h. p.	2-400 h. p.
Steam pressure, gage	140	140
Temperature of feed, degrees F.	199	
Boiler h. p., basis 34.5 pounds of water from and at 212	434.	
Heating surface of boilers, square feet	3675.	7350.
Heating surface per boiler h. p., square feet	8.32	
Barometer reading, inches of mercury	29.96	
Quality of steam, per cent	99.1	
Ratio, pounds of water evaporated to pounds of fuel oil, actual	12.47	
Ratio water evaporated to fuel oil, from and at 212	13.14	
Barrels of fuel oil per hour (315 pounds)	3.625	6.33
Pounds of oil per minute	19.03	33.23
Pounds of fuel oil per i h. p. hour	1.736	
Pounds of oil per useful water h. p. hour	2.084	1.892
Heat value of fuel oil, B. t. u.'s per pound	18,790.	18,790.
Heat equivalent of fuel oil per minute	357,550.	624,500.
Pounds of steam per minute	241.4	
Pounds of steam per i. h. p. hour, used by engines, oil burners, vacuum, and feed pumps	22.02	
Heat required to produce total steam per minute	241,500.	
Ratio of heat in steam to that in fuel oil (boiler eff.)%	67.5	
Heat equivalent of i. h. p. per minute, B. t. u.'s	27,900.	

	August 8	August 9
Ratio of heat equivalent of i. h. p. to heat in total steam	.1155	
Ratio of heat equivalent of i. h. p. to heat equivalent of fuel oil	.078	
Heat equivalent of water, h. p. per minute, B. t. u.'s	23,242.	44,710.
Ratio heat equivalent of w. h. p. to heat of total steam	.0961	
Ratio heat equivalent of w. h. p. to heat equivalent of i. h. p.	.833	
Ratio heat equivalent of w. h. p. to heat in fuel oil	.065	.0716
Duty, per million heat units in fuel, millions of foot lbs.	50.5	55.7
Duty per 1,000 pounds of dry steam, millions of foot lbs	75.4	
Cost per barrel, fuel oil, cents	65.	65.
Cost of fuel oil per hour	$2.36	$4.12
Amount of water pumped, gallons per minute	68,530.	130,700.
Cost of fuel to raise 1,000,000 gallons one foot, cents	1.81	1.63
Cost of fuel to raise one acre-foot one foot, cents	.556	.501
Cost of fuel to raise water 20 feet to irrigate one acre two feet deep, cents	22.24	20.05
Cost of fuel to raise water 20 feet to irrigate one acre two feet deep, fuel oil at 50 cents per barrel of 42 gals., cents	17.11	15.42

DISCUSSION

PROF. R. C. CARPENTER The high efficiency which is shown by the rotary pump, the test of which is given in Professor Gregory's paper, is remarkable. In accordance with the paper the total losses existing between the engine piston and the water delivered is only 16.7 per cent. The friction and other losses in an engine of the class shown, namely, a horizontal tandem-compound Corliss engine, is not often under 10 per cent. The friction losses in the pump driving gears can hardly be less than 2 per cent unless they are of unusually perfect construction. Calculation of this kind would indicate, if the results of the tests are correct, that the efficiency of the pump must have approximated 95 per cent, an amount which in my opinion is difficult to attain with the construction shown, since the pump is subjected to friction and hydraulic losses as well as leakage.

2 In connection with the test of the Ontario Power Plant at Niagara Falls in 1905, I made a great many experiments respecting the measurement of water with Pitot tubes of different forms and in this work I was assisted by able and experienced hydraulic engineers. As a result of the investigation I found that Pitot tubes were accurate

and reliable when used under proper conditions for the measurement of water. I found that the constant for the Pitot tube changed very greatly with different conditions of use, and that in order to get reliable results it was necessary to calibrate it under the identical condition of use. The result sheet of the paper shows that the Pitot tube readings gave discharge results which agreed very closely with that calculated from the displacement of the pump.

MR. A. M. LOCKETT. Professor Gregory's paper is very interesting to me for the reason that it confirms a belief which I have always entertained that a rotary pump of the type described is a very efficient machine for handling large volumes of water under low heads, but I have always believed that the practical difficulties in the way of the continuous operation of such pumps under the average working conditions called for in irrigating the Southern rice fields render it extremely doubtful whether, in spite of the exceptional efficiency, the machine should be looked upon as a good commercial investment.

2 I am not sure that the points upon which I wish to touch properly come under a discussion of Professor Gregory's paper, because this paper is an account of a scientific test, the accuracy of which is not questioned, but upon the grounds that a paper of this character, when read by possible purchasers, will undoubtedly carry great weight, I think that it would be to the interests of the public if Professor Gregory would answer the questions which I propose to ask, or prepare another paper dealing with this problem from the standpoint of a commercial investment. I would like to ask Professor Gregory whether he has made any investigation along these lines and if after such investigation he has come to the conclusion that the rotary pump is a better commercial proposition than the centrifugal for irrigating the rice lands of the Southwest? It occurs to me that in the selection of the proper type of machine for any given work, the efficiency is not the only consideration; first cost, liability to breakage, the cost of renewing parts, the ability to force beyond rated capacity, and such like considerations are in most cases equally as important, and, in the irrigation of land, are of first importance. I would submit for this consideration the following points:

a On the basis of 83 per cent efficiency for the rotary and 70 per cent for the centrifugal, will the additional first cost be justified as a commercial investment?

3 Taking Professor Gregory's estimate of fuel cost for the Neches plant at $4.12 per hour with the 83 per cent plant will mean a saving of about 77 cents per hour or $18.48 per day of 24 hours. Taking

ninety full days as the average pumpage in t L siana and Texas irrigation districts means a yearly saving in fuel of $1663. Money in that part of the country cannot be had for less than 6 per cent and allowing 7 per cent for depreciation, we find that a saving of $1663 would justify an additional first cost of $12,791. What is the additional cost of four of these machines over centrifugal pumps of the same capacity? My impression is that this difference will be more than the amount named.

b Can these pumps be depended upon to deliver their rated capacities without danger of breakage?

4 In Mr. Wilkin's paper upon this same subject in Volume 24 of the Society's Transactions, he uses the following language:

"An interesting experience was l ad with two pumps, each to have a capacity of 25,000 gallons per minute lifted 31 feet coupled direct to a Corliss engine, running at about 67 revolutions per minute. We designed them with two air chambers on the discharge and two on the suction side of the pumps, placing them as near as possible to the impellers, the air chambers having connections to the pumps seven inches in diameter. When we began to operate the pumps we found that they would run smoothly up to 50 revolutions, at which speed a powerful water hammer occurred. We attached an indicator to the discharge side of the pump 18 feet below the upper water level and found that the pressure there varied from 5 or 6 pounds vacuum to 30 or 40 pounds pressure. The action on the suction side was similar, except that the vacuum was 12 pounds and the pressure rose slightly above atmosphere."

5 Evidently, there was something serious going on in that pump. You will note that the pump was working under an actual lift of 31 feet. On the assumption that the maximum pressure on the discharge of 40 pounds occurred simultaneously with the maximum vacuum on the suction of 12 pounds, we have a momentary head of 120 feet or an overload of more than 300 per cent, not taking into consideration the difference in elevation of the two gages.

6 If these strains existed in the pumps referred to with four air chambers, it would be interesting to know what proportion of such dangerous shocks have been removed by the modified air chambers in use on the pumps under discussion. I would ask Professor Gregory if he took any indicator cards from the pumps.

7 I would also call attention to the fact that in Mr. Wilkin's paper, he refers to the plant tested by Professor Gregory as consisting of four units each of 35,000 gallons a minute capacity or a total of 140,000

gallons, whereas the capacity as shown by Professor Gregory's log is 130,700.

c Can these pumps in an emergency due to breakdown of other units be safely forced above their rated capacity as can be done with a centrifugal pump?

8 Manifestly in a pump handling the immense mass of water contained in the pump itself and the suction and discharge pipes connected thereto, in which the water is propelled in a series of impulses, the inertia of this water becomes a very formidable proposition and one naturally assumes that even though the air chamber is ever so large, there is a point beyond which the machine can not be safely operated. By reason of the high cost of these machines, I suspect that the manufacturer is almost compelled to rate his machines at that maximum safe speed, and if such is the case, it occurs to me that the machine for practical use does not compare favorably with the centrifugal, where the limit to the speed is the limit to the engine speed and power.

d Is this pump liable to breakage by reason of foreign substances entering through the suction pipe? What will happen if a nut or bolt should find its way between the two impellers?

9 I have had to do with a number of irrigating plants and I know that in nearly every plant, sooner or later, the pump will be called upon to handle many things beside water.

What would be the effect on this pump if the water carried large quantities of sand? I happen to know of one irrigating plant where so much sand has passed through the pump that the canal, 150 feet wide, is practically filled for half a mile, and the centrifugal pump is showing high efficiency; this after four years of such service.

10 My object in calling attention to these points is that, by reason of Professor Gregory's great reputation as an expert in this class of work, his report will, no doubt, be taken as conclusive argument in favor of the rotary pump as an irrigating machine, and I have very good reason to believe that, in spite of its superior efficiency under test, the rotary pump is not so good a commercial proposition as a high efficiency centrifugal. There are centrifugal plants in the Southwest showing as high as 70 per cent combined efficiency, and of a total of nine large pumps installed by the writer during the past six years, not one has had a breakdown of any kind nor involved any expense whatever in the way of repairs to the pumps proper.

THE AUTHOR The writer wishes to state that he had no preconceived theories to prove and no other object in view, in making the tests described in the paper, but to ascertain the truth.

2 The Abbeville plant was tested during the summer of 1905; it was the first of many plants tested that season. The indicators were new; they had never been used before. They were carefully calibrated and behaved in a satisfactory manner throughout the test. The mean combined efficiency of the pump and engine was 81.77 per cent. This was the only rotary pump tested in 1905 but several tests were made of centrifugal pumps of various types; some of these had extremely low efficiencies. In all the tests every precaution was taken to guard against error; the general method of testing all the plants was the same.

3 The test of the pumping plant of the Neches Canal Company was made more than a year after the Abbeville test. The instruments used were the same in both with the exception of two additional indicators, required in the latter test; all were carefully calibrated. The current meter had been re-rated.

4 Considerable experience with the Pitot tube has given me confidence in its accuracy. I can see no reason why the constant of the tube should change, whether the tube is used in an open channel or under pressure in a pipe, and I would be glad to see experimental information bearing on this point. The current meter readings and those obtained by means of the Pitot tube agree exactly, in the average, with the displacement of the pumps. The two instruments were used in order that results could be compared and checked. Evidently the errors in the current meter and the Pitot tube are the same; in numerous other tests they have given practically identical results. It seems to me probable that both were correct within a possible error of 1½ per cent. Had a weir been used to measure the quantity of water (153 cubic feet per second) an error of 1½ per cent would not have been unusual, in fact that amount of error would be expected. This is all that was claimed for the accuracy of the water measurements.

5 The Connersville Blower Company constructs its pumps with extremely small clearances; the slip must be correspondingly small. The average slip, as shown by readings obtained by the two instruments used to determine velocity in the Neches test, was *nil*. For an intelligent discussion of the slip of a rotary pump, the clearance must be known; even then the slip cannot be computed with accuracy, but this knowledge will aid in forming an estimate, more or less just, of the amount of the leakage. In the pumps tested the clearance

between the impellers and the casings or "cylinders" is about 0.024 of an inch. The clearance at each end of the impellers is about 0.012 of an inch, while that between the two impellers, at their line of contact, is about 0.048 of an inch. This information was furnished by the man who assembled the pumps and erected the plant. The dimensions were obtained by actual measurement; the above values are averages. From the known areas due to the clearances and the meas ured head, the amount of leakage or slip is found by an approximation, necessarily crude, to be about 1½ per cent of the water discharged.

6 The writer must take issue with Professor Carpenter as to the probable mechanical efficiency of the engines at the Neches plant. There are a great many published reports of tests that show mechanical efficiencies of from 93 to 94 per cent for engines with apparently no less friction losses than those of the Neches plant. Reference will only be made to results obtained by Professor Carpenter or in experiments made under his direction. In Volume 16, p. 929, of Transactions, in the report of tests of the Sibley College cross-compound Corliss engine, at full load, the mechanical efficiency is given as 93.7 per cent. The engine has cylinders 9 inches and 16 inches in diameter, stroke 36 inches. The same paper reports tests of a simple Corliss engine in which the mechanical efficiency is as high as 97 per cent. Certainly the tandem compound engines at the Neches plant, running at from 55 to 58 revolutions per minute might have as high a mechanical efficiency as a smaller, cross compound engine running at about 85 revolutions per minute.

7 In the "Sibley Journal," Volume 15, p. 13, a test of two simple engines in the lighting and power station at Cornell University, is reported. The mechanical efficiency of an 85 horse power McEwen and a 25 horse power Ideal engine is given as 94.3 per cent.

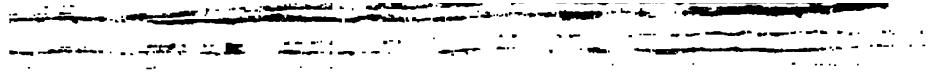
8 In the "Sibley Journal," Volume 19 p. 60, is the report of a test made at Cornell on a Reeves simple engine, which developed at a maximum, nearly 170 horse power. The mechanical efficiency when the engine was run condensing, is given as 95.8 per cent in one case and above 95 per cent in four different cases.

9 The engines of the Neches plant had been running for several weeks previous to the test; they were limbered up and in good adjustment; the cards show the load to be well distributed on the two ends. It, therefore, seems to me altogether probable that the mechanical efficiency of the two engines tested was not less than 93 per cent. The combined efficiency of the engines and the pumps was 83.3 per cent. If we assume the efficiency of the engines as 93 per cent, the efficiency of the pumps would have to be about 89.6 per cent. It

must be kept in mind that the losses in the suction and discharge pipes, due to friction, to loss at intake and the velocity head thrown away at the end of the discharge pipe, are charged to the pump. The mean velocity is only a little over six feet per second and the losses consequently small; a computation shows the sum of these losses to be about 4 per cent of the total head.

10 Professor Carpenter estimates the friction loss in the gears at 2 per cent; this leaves 4.4 per cent for hydraulic losses in the pump only. The rotary pump is more nearly comparable to a piston pump than to a centrifugal pump. There may be a little more eddying of the water in the rotary pump than in piston pumps, but in the latter there are often sharp turns to be made in the water passages leading to and from the water cylinders and the valves have to be passed with a small accompanying loss. Pumping engines of the free piston type often have mechanical efficiencies above 95 per cent; the loss being in part on the steam end and in part on the water end. In the case of the rotary pump, the only loss under consideration is within the pump and is exclusive of the friction of the gears. It seems to me altogether probable that the losses in the pumps tested were not in excess of 5 per cent.

11 In making comparisons between various types of pumping plants and especially in deciding on the pump to be used in a particular case, consideration must be given to reliability, first cost, and running expenses, the last include depreciation and repair, interest on investment, wages, and cost of fuel. A part of the running expenses will be constant from year to year as they are pro-rated on the investment. The quantity most liable to fluctuations is the fuel bill. In designing a pumping plant all these variables must be carefully considered, each separate problem worked out on its merits, and the plant designed for the highest financial efficiency. The general method of treating the question may be found in Bulletin 183, Office of Experiment Stations, U. S. Dept. of Agriculture. In that publication I have discussed the various types of pumping plants for a particular set of conditions, including oil at 50 cents per barrel. Without going into further details, the conclusion was reached that a high grade centrifugal pumping plant was the best investment for the assumed conditions. However, during the past year the price of fuel oil has more than doubled, and it was only necessary that oil cost about $1.50 per barrel, to make the plant using rotary pumps an equally good investment, as the cost of irrigating an acre with the two different types of pumping plants would be the same. As fuel increases in cost the amount that can be saved by an economical plant will become



more and more important and the additional first cost justified by the saving in the fuel will be proportionally increased.

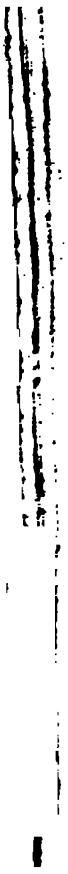
12 The experience of the Neches plant would seem to indicate that rotary pumps may be operated without danger of breakage. The pumps have been operated for four seasons, and I am told have often been run above their rated speed of 60 revolutions per minute without developing troubles of any kind. Difficulties due to fluctuations in the suction and discharge pipes are overcome by the air chambers. A small Westinghouse air pump, such as is used in locomotives, supplies air to the air chambers on the discharge side of the pumps. Sight glasses show the position of the water level. No indicator cards were taken from the pumps or the discharge pipes during the test; there was an entire absence of water hammer. The pumps were operated without noise and they were satisfactory in every way.

13 Undoubtedly centrifugal pumps can be forced above their rated capacity much more easily than can rotary pumps, but the increase in capacity is usually attained at a sacrifice of efficiency and cost of operation. However, cases occasionally arise in which this sacrifice is very gladly made.

14 With the flexible couplings described in the paper, there is no danger from breakage in case wood or other hard substances get into the pump. The babbit keys shear and then "howl" as the engine continues to revolve. This has happened several times at the Neches plant and no serious breakage has resulted.

15 The question as to which type of pump is less likely to give trouble is one on which the men who operate the pumping plants do do not agree. Rotary pumps are not "fool proof" but any high grade plant requires skilful handling and it is false economy on the part of the owners to have any but high grade men to run such irrigation plants.

16 Pumping plants using rotary pumps in Louisiana and Texas have made splendid records for fuel economy; the saving in fuel is not entirely due to the type of engine usually employed but is due also to the high mechanical efficiency of the pumps.



No. 1133

ON THE EVOLUTION OF GAS POWER

By F. E JUNGE, BERLIN, GERMANY
Member Verein Deutscher Ingenieure

1 The conservation of the world's natural resources, both by economic methods of production and by scientific means of transformation, tends toward the stability of modern industry and is essential to the life and prosperity of future generations.

2 Great savings in the world's supply of fuel materials cannot be made unless recourse is had to the elimination of traditional methods of production which have largely stood in the way of economical progress, and to the adoption of novel means of generation which effect the transformation of fuel energy into mechanical power in a more direct and efficient way. To the achievements already realized in this direction, there has lately been added one that even a few years ago would have been deprecated by the conservative engineer as a more or less fantastic and impossible dream, namely, the gasification of inferior grades of fuel, the utilization of waste products, and their direct conversion into useful power in gas engines.

3 Who can help admitting that the employment of gas power has actually become a factor of consequence in the world's total energy output when it is considered that in Germany, a small country of four-fifths the size of Texas, there are today in the iron and coal industry alone in active service or in contemplation, 136 gas blowing engines with 161,300 h.p., 200 gas dynamos with 206,300 h.p., 11 gas engine roll drives with 17,000 h.p., and 47 coke oven dynamos with 40,000 h.p., besides 4 engines with 1500 h.p., for other purposes, or a total of about 400 large gas engines with a combined capacity of 420,000 h.p.

4 As in the case of every other technical innovation the early period of growth of a novel method of energy making must needs be sporadic and must encounter competition in order to gain strength together with progressing expansion. Isolated inventions even if

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commercially sound will fail unless technical science and the development of appliances are correspondingly advanced.

5 The Diesel engine stands as an example of this fact. Conceived some twenty years ago, it was not made a commercial machine until quite recently. The difficulties in finding suitable materials that would stand the enormously high temperature and pressure stresses, the absence of automatic machinery and other facilities which would allow its manufacture to be put on a commerical footing, the impossibility of finding among the rank and file of engineers a sufficient number of men that could be trained to attend the new engines successfully—all these things proved obstacles in the path of the industrial adoption of this new invention. We were all convinced at the time that it marked a truly wonderful link in the chain of energy transformation, despite the fact that the theoretical predictions of the inventor were not borne out in later practice.

6 A similar experience was true of the Brayton engine, of which we find mention in Dr. Lucke's "The Heat Engine Problem."[1] Without indulging in visionary prophecies, it may be said that the working process of this engine is bound to find more general recognition in future practice if the ideal, which we are striving after in gas engine engineering is to be realized, namely, "regulable and enforced combustion of a precompressed dynamic medium of air and fuel in quantities determined by the cut-off from the engine governor according to the load," or speaking in terms of the cycle: "a process composed of adiabatic compression, heat influx at constant maximum pressure, adiabatic expansion, and heat efflux at constant atmospheric pressure." But Brayton was hopelessly ahead of his time, and glancing over the discussion which followed the reading of the paper mentioned, you will find that even Brayton's distinguished interpreter was not understood. And it is likely that even today there are but few competent observers who will admit that there is salvation beyond the present standard design.

7 This presentation, however, could not be complete if reference were not made to the probable future development of gas prime movers. For the ideal process of continuous combustion, it matters not whether the fuel burnt is gaseous or liquid, the distinction being a mere incidental and external one. With every internal combustion engine the goal is the removal of energy from the gas in expanding from a higher to a lower tension, preferably down to the limit of atmospheric equilibrium. All present types of gas, oil, gasolene, and alcohol

[1]See Transactions, Volume 23, p. 202.

engines are included under this designation. They also are continuous combustion engines in a certain sense, though this feature is an unsought for and undesirable phenomenon accompanying the peculiar working process. The term "explosion" is incorrect when applied in this connection.

8 In order that combustion be brought about it is necessary that air and fuel should be introduced in correct proportions under similar cyclic conditions during the entire range of load. Further, the two constituents must be perfectly mixed when entering the cylinder, in order that each fuel molecule may find its corresponding quantity of oxygen which is necessary to support combustion. Finally, since

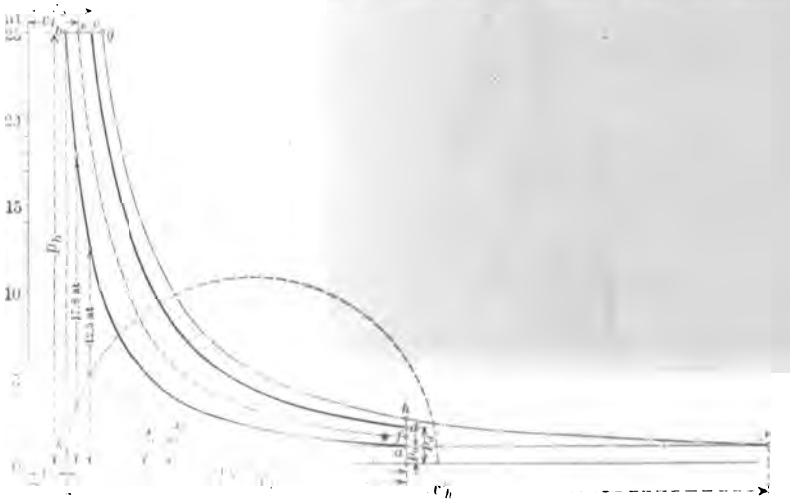

FIG. 1 THEORETICAL WORKING CYCLE OF DIESEL ENGINE

combustion of the charge particles causes a rise in internal pressure, while the initial piston stroke tends toward its reduction, the rapidity of heat influx must bear a certain fixed relation to the piston speed, in order that the two counteracting influences may be equalized and continuous combustion at constant pressure be secured. In the Diesel engine, of which Fig. 1 shows the theoretical working cycle, none of the above conditions are brought about. We have a constant body of air to support combustion, a pressure of the injected oil vapor which does not bear a fixed relation to the varying internal pressures, and, therefore, a speed of fuel influx which is irregular and one which in no way corresponds to the piston speed of that period. Nor does each fuel molecule on entering the cylinder find at once its corresponding quantity of oxygen. This feature retards ignition and flame

propagation and makes the combustion a seemingly continuous one, though what we actually see is after burning.

9 It was only after long and costly experiments with various forms of inlet nozzles that an artificial retardation of heat influx was finally obtained and the desired pressure balance secured. Yet to the casual observer, the Diesel engine appears to be representative of the continuous combustion type. Notwithstanding these deficiencies, the thermal results of the engine are so excellent that it is truly indicative of what we may expect on a further approach to the ideal process.

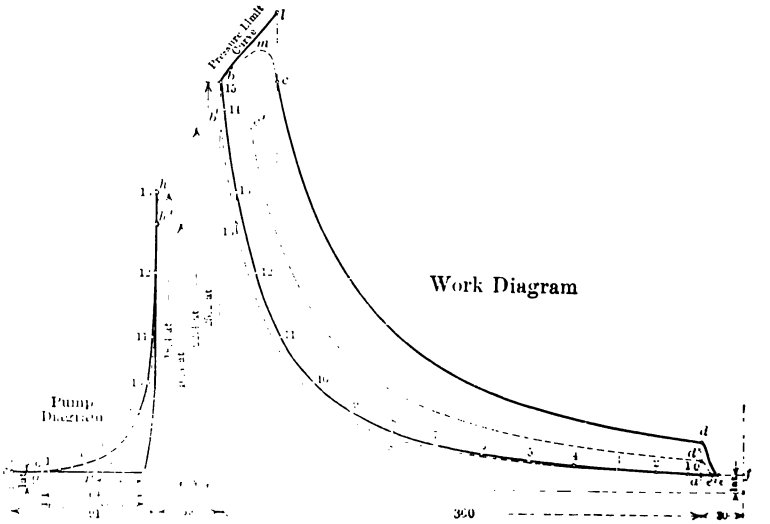

FIG. 2 THEORETICAL WORKING CYCLE OF CONTINUOUS COMBUSTION ENGINE (WEIDMANN)

10 Attention is called to an essay by Carl Weidmann, D.E., of the Technische Hochschule, Aix la Chapelle, Germany, on the enforced regulation of combustion in heat engines. In this he describes his new engine, designed with a view of utilizing the experience gained with the Diesel engine. The Weidmann engine is similar to that of the Diesel in that gasified fuel is injected into a highly compressed body of air in the working cylinder, with the remarkable difference, however, that a corresponding amount of air is introduced with the fuel by a receiver piston moving at a rate corresponding to the speed of the working piston. The fuel and the air are so intimately mixed that combustion must regularly occur. Fig. 2 gives a theoretical diagram of the proposed process, from which the inventor calculates a thermal efficiency of 50 per cent.

11 The engines of the Otto type, as constructed by leading manufacturers, have been developed to a state of high perfection. Their deficiencies and incidental phenomena have been so far eliminated that the enthusiastic advocate of gas power is apt to overlook them entirely. Yet of ten indicator cards taken under identical conditions from the same engine, every one will reveal its fundamental weakness,

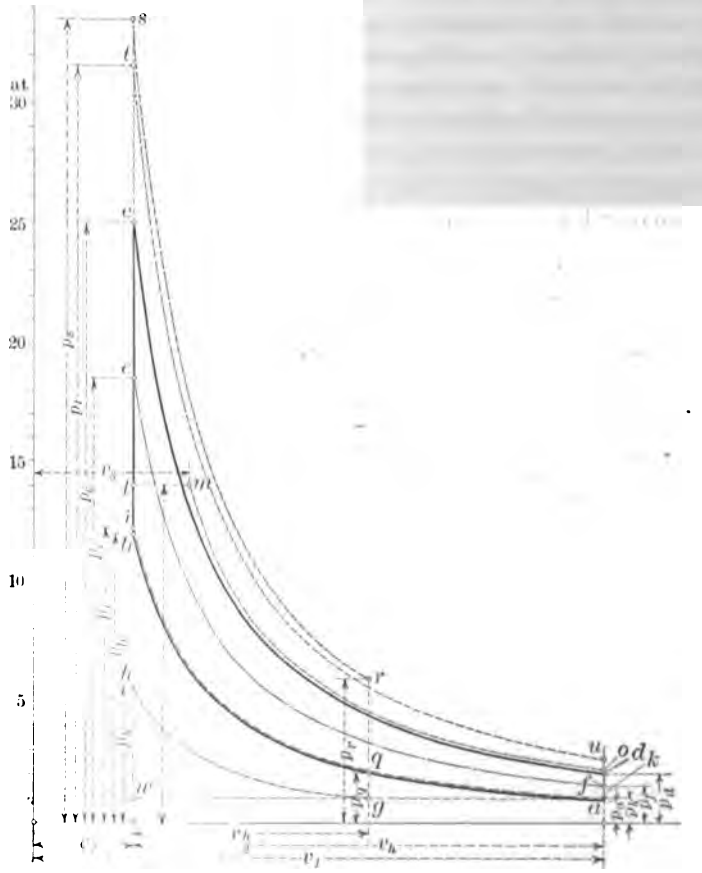

FIG. 3 THEORETICAL WORKING CYCLE OF OTTO ENGINE

namely, the impossibility of controlling the combustion which is the most important function of the working process. The irregular and imperfect mixing of the charge constituents, the possibility of premature ignition and after burning are drawbacks of the present working cycle of gas engines. Of these Fig. 3 gives the diagrammatic representation.

12 Various attempts to improve on the working process as carried out in standard engines (as by prolonged expansion, compounding, and water injection) have proved to be entries on the wrong side of the balance sheet. The drawbacks common to all of these so-called improvements are increased bulk, weight, first cost, and negative work of expansion. The best method of prolonging expansion is by high compression of the dynamic charge before combustion. The most economical way of reducing heat losses through the exhaust is by utilizing the same for raising steam in an exhaust boiler. As high as 160 lbs. per sq. in. can in this way be generated and used for factory heating or other purposes. Generally 10% or more of the total output can be recovered from the exhaust of gas engines. Even the interesting experiments of that distinguished authority, Mr. Dugald Clerk, in which he tried to improve on the working process by increasing the

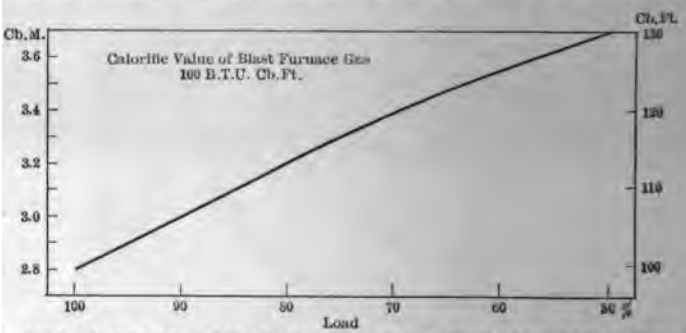

FIG. 4 GAS CONSUMPTION OF OLD TYPE BLAST FURNACE GAS ENGINE FOR ONE EFF. H. P. HOUR AT VARIOUS LOADS

density of the charge before compression, have failed to effect any considerable advantage. The additional neutral gas he used, though it reduces temperatures all around, tends to retard the influx of heat, and thereby promotes after burning and heat loss through the exhaust. The combustion process pure and simple, as used in the standard types of engines (the Nuremberg, the Koerting, the Oechelhauser, the Cockerill, the Westinghouse, the Reichenbach, etc.) gives the highest economic efficiency attainable with the Otto cycle.

13 Another practical drawback, and one that cannot be overcome by the highest engineering skill because inherent in this cycle, is the lack of overload capacity in gas engines and the fact that the range of economical load is limited to only a fraction of the total. This is by no means as small as is usually held. Fig. 4 shows the rate curve of gas consumption of large blast furnace engines of an earlier design as obtained on the Continent from several years of actual practice. It is

seen that the line of gas consumption per B.h.p. presents characteristics similar to those of the steam engine, rising from 100 to 130 cu. ft. when the load drops from full to 50 per cent of the maximum. Another unfortunate characteristic of the gas engine is its lack of overload capacity. This often militates against its adoption and is especially felt when operating urban and interurban railway plants. It can be compensated either by a storage battery of sufficient capacity, or by an auxiliary steam turbine system as proposed by Stott, or by the installation of spare gas engine units with a corresponding equipment for gas storage or instantaneous generation. There is no prime mover that lends itself better to the latter application, especially as since the employment of compressed air, gas engines can be started quite as easily as steam engines.

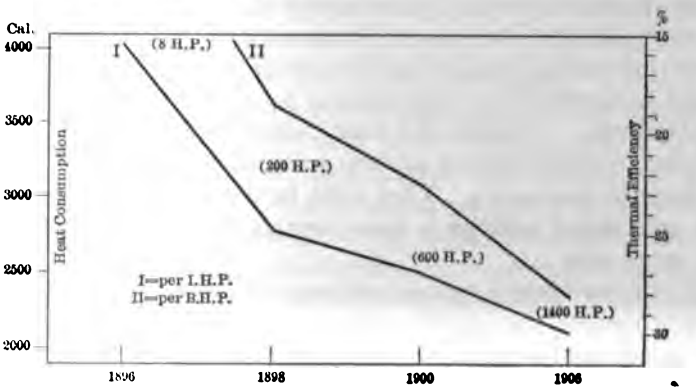

FIG. 5 TABLE SHOWING INCREASING EFFICIENCY OF GAS ENGINES (BELGIUM)

14 Since the majority of failures of gas power plants have been due to the fact that the engines selected were too small for the maximum duty which they were expected to perform, the rating of gas engines should be standardized and the public should be advised by the manufacturers that for a service with heavy overloads, such as occur, for instance, when driving rolling mills, the capacity of gas engines must be considerably larger than that of steam engines.

15 Though the ideal after which we are striving is still far from what we have actually attained, it would be wrong to conclude that the present type of gas prime movers is not on a high level of excellence, not only as an economical, but as a reliable machine. Just as the steam turbine cannot be regarded as having reached its highest state of perfection and yet is a commercial engine of the greatest possibilities, so it is with the gas engine. After having passed out of the costly experimental state and after having reached a condition of

standard design, its manufacture, when properly directed, is now as profitable to the engine builder as its application is to the power consumer.

Fig. 5 shows how improvements of design and construction have gradually lowered the consumption of heat per unit output in gas engines.

16 The variety of earlier forms has now been reduced to two classes, (1) the double acting tandem four cycle engine, and (2) the double acting two cycle engine. The single acting type of each is only applicable in the smaller sizes. Each type has its disadvantages and each its special field of application. The four cycle is used for general power work and the two cycle for blowing service, pumping and wherever variable and low speeds are essential. There is a tendency towards the employment of higher speeds in large gas engines, in order to reduce the first cost also of the generator. Therefore, since the peculiar process of charging with an open exhaust limits the two cycle engine to speeds of from 80 to 100 as a maximum, this type is at a disadvantage. It would lend itself better to the building of vertical engines. Vertical engines promise great savings in manufacture and of course in floor space. They must be developed in order to compete with steam turbines in space economy, and also for purposes of ship propulsion.

17 Of the various methods of regulation applicable in large gas engines, namely, the quality, quantity, and combination system, the last named (as developed by Reichenbach and Mees) is superior to all, because it reduces the calorific value and the quantity and therefore the compression of the mixture at the lower loads less than do the others. Therefore, more regular and efficient combustion is secured with decreasing load and lean mixtures, especially when the point of ignition is automatically advanced.[1]

18 Regarding the latest thermal performances of internal combustion engines, attention is called to, (1) a 14 h.p. Manienfelde alcohol motor and a 70 h.p. Diesel oil engine showing on test an indicated thermal efficiency of 41.7 per cent, (2) a 20 h.p. Gueldner gas engine running on city gas with 42.7 per cent, and (3) a 500 h.p. Borsig-Oechelhauser coke oven gas engine with 38.6 per cent. These figures refer to approximately full load conditions. Therefore, one h.p. indicated

[1] For detailed information on problems of design, refer to Dr. Lucke's "Gas Engine Design," to Gueldner's "Design and Construction of Internal Combustion Engines" and to the author's treatise on "Design, Construction, and Application of Large Gas Engines in Europe," published in "Power," New York, beginning November, 1905.

in the cylinder of the best gas engines so far on the market requires the expenditure of only 1490 calories or 5900 B.t.u. The economic efficiency of the latest types of gas engines, based on the actual output of available work is, therefore, between the limits of 32 and 33 per cent.

19 Engineers who either have antagonistic attitudes toward the above undeniable performances or are prone to adopt them, usually try to belittle their economic importance. They point out that in proportion to the relative value of the several elements which determine the commercial economy coefficient of a heat power plant, the factor of fuel expenditure is not the most important item of expense. They say, further, that it is often completely overborne by the fixed charges, especially by the interest on the initial cost of equipment, which is for gas still higher than for steam per h.p. output, though some manufacturers have succeeded in almost equalizing this difference. Yet it must be borne in mind that even so small a saving as 1/100 of a cent per h.p. hour amounts, with a plant of 1000 h.p. output and 3000 working hours, annually to a total of $300 a year. Figuring on 10 per cent amortisation, the improved machinery which effects this saving may cost $2000 more and will yet give a net annual saving of $100. Since the reduction of gas consumption by the adoption of gas engines in place of gas fired boilers and steam engines is generally in the proportion of 3 to 1, the factor of fuel cost is by no means a negligible quantity in the h.p. hour calculation. This is especially true where power is directly needed, and, with low gas economy, recourse must be had to costly boiler coal, as is the case in iron smelting plants and collieries. The savings effected by the installation of cheaper turbo-dynamos do not offer anything near an adequate compensation for the increased expenditure in plant fuel cost.

20 In large power plants the item of fuel cost is composed, besides the price for the coal, of the expense of handling it between the car and the ash pile, including sufficient fuel storage capacity to guarantee permanence of production during all emergencies, and especially against interruptions in the supply service, such as are occasioned by strikes, railroad accidents, car or locomotive famines, etc. It is obvious that with the reduction of the fuel bill to one-third, the interest on the amount of capital locked up in the coal stored, and in the storage equipment, as well as the cost of operation and upkeep, are correspondingly reduced. With the same investment the gas power plant can tide over periods of fuel shortage, and keep up production when the steam competitors would have to shut down.

21 The question of fuel valuation which comes up when studying

the comparative cost of power plants and their economics has still another aspect. The present attitude is that the cheaper the fuel the less profitable it is to use gas power in a plant. If, therefore, a gas power plant cannot effect a saving in the cost of labor, supplies, and repairs, over what is obtained with steam, there will be a definite economic limit fixed which is determined by the price of fuel, and beyond which there is apparently no hope for gas power. Curves have been plotted showing diagrammatically the comparative cost of a gas and a steam installation. When first plotted they were equal for coal in the neighborhood of $2 per ton. A year later it was shown that the two cost lines crossed at a point corresponding to a value of coal of one dollar per ton. It has been suggested that a further reduction in the price of gas power machinery may eventually tend to effect a crossing of the two curves at the zero point of the cost of coal. This would mean that when fuel can be had for nothing, both plants can deliver power at the same cost.

22 In the iron and coal industries blast furnace and coke oven gases are available as a by-product and may be used for the generation of power. These gases were formerly wasted, either by inefficient methods of transformation or by blowing them into the air. They were, therefore, called waste gases and were marked in the columns of plant economics as having no commercial value whatsoever. It is now regarded as correct to appraise these gases at a rate, (1) corresponding to that of a certain weight of coal of thermal equivalence, (2) to the amount of steam that can be generated by a certain measure of both fuels, or (3) to that of some other standard depending on local conditions.

23 It is apparently a mistake to regard any kind of combustible matter as having no value. There are, of course, cases especially in a new country with undeveloped fuel resources and desert districts where that value is not immediate and practical.

24 There is so much being said just now about the realization of ideals in industrial pursuits that it is surprising to find in the conservation of fuels no trace or effect of such doctrine. All power plants are designed with the ultimate object of being producers of wealth for the present owners and with no regard for future activities. But even when guided by purely material motives, it is well to remember that the valuation of property is subjected to great fluctuations brought about by the rapid expansion of industries and the development of new branches.

25 An iron smelting plant having steam turbines and gas fired boilers in the power station may at present consume all of its available

gas in the blast furnace and steel works. If a corresponding allotment for rolling mills is to be added, or if other industries are attracted to settle in the neighborhood, or if some community or city would build up in the immediate vicinity of the plant to whom it might be desirable to sell power at a profit, then the works management would be confronted by the necessity of either buying good steam coal, or else of consigning steam turbines and boilers to the scrap heap and of replacing them by gas engines able to generate the required additional energy from the available gases or other waste at no additional heat cost.

26 With the rapid spreading of industries at this time, it is wise to design power plants with a view to prospective rather than to immediate earnings. Therefore, comparisons of the cost of different types of plants are not only for the most part inaccurate, but are also of local and momentary value. Earning capacities depend on the market for the output. Markets commend the employment of the most economic methods of fuel transformation, utilization and conservation, rather than the adoption of methods which appear to secure the maximum immediate profit.

27 This question of the economic relation of a gas to a steam plant has passed into an entirely new phase since it became possible to directly gasify such fuels as cannot be efficiently used for raising steam under boilers. This brings us to the other important factor in the evolution of gas power, namely, the producer, which has helped to conquer for the gas engine the enormous and practically unlimited field of application which it is just beginning to enjoy.

28 The United States Geological Survey has been conducting a series of tests at St. Louis to ascertain how the different grades of bituminous coal are suited for producer work; and also how the results compared to what was obtained when firing these coals under steam boilers. A résumé of these tests was presented at the last annual meeting of this Society by Professor Fernald. Among other things the interesting fact was developed that the fuel consumption of the steam plant increased comparatively much more rapidly with the poorer grades of coal. I do not know whether these tests have been continued and extended so as to include the examination of fuels of still greater inferiority, such as cannot without difficulty be burnt under boilers. In Germany, there are three or four types of producers in operation which have been working successfully on such material as city refuse, culm banks, etc., containing often not over 20 per cent of combustible matter, and yet doing continuous service in connection with gas engines.

29 If, therefore, gas producer power plants using the higher grades of coal, such as anthracite and coke, have been able to compete with steam plants using inferior grades of bituminous coal, the situation is now completely changed in favor of the first claimant, since we have succeeded in making gas from such fuels as hitherto escaped utilization entirely.

30 The gas producer in its present form is a comparatively modern creation. It is developed from the regenerative furnaces such as were employed, among others, by Siemens in the process of steel making. It received early attention in England and France. The names of Dowson and Dr. Mond must be mentioned among those who took an active part in the vigorous development of earlier forms. The latter is especially known as having evolved a producer gas system suited to the utilization of low grade bituminous coal with the recovery of by-products in form of sulphate of ammonia, which latter has found an extensive use as fertilizer in agricultural pursuits.

31 These earlier producers were of the pressure type. In them steam and air were blown through an incandescent fuel bed, and the gas thus generated was stored in a holder. Their sphere of application was considerably reduced by the invention of the suction producer, which was first developed by Benier in France, and by Koerting in Germany. Its apparent advantage consists in that the gas making apparatus is under suction instead of under pressure, since air and steam are drawn through the fuel bed by the aspirating action of the engine piston. No extra coal fired boiler is required for raising steam. This performance is left to the sensible heat of the gases leaving the producer. The bulky gas holder is also eliminated.

32 Suction gas plants are, therefore, very simple, safe, and reliable in action, and have found an extensive field of adoption in Europe and also a limited sphere of usefulness in this country. The lower grades of American fuels present characteristics less suitable for gasification than are possessed by the European coals. It cannot be said that the gasification of caking coal is an accomplished fact. In Europe there is no lower limit in grade of fuels. At the same time another and no less important problem has been solved, namely, the cleaning of the gas from tar and other impurities which are formed during the transformation process. This is done by converting the tarry products into fixed gases in the producer proper, either by blowing or drawing the unstable volatiles through the principal or through a second zone of combustion where they are transformed into stable constituents which do not separate from the gas when being cooled. No complex and bulky cleaning apparatus is required, except an ordinary wet

coke scrubber and means for drying. The question of tar extraction and disposal is thereby effectually solved and the gas is enriched accordingly. It appears even that the utilization of other available tar as additional fuel for use in gas producers gives promise of success.

33 Regarding the general design and the constructive principles of gas producers, we cannot refer to a condition of standardization such as obtains with gas engines. This would be true even if fuel characteristics were identical all over the world, since there is as yet no accurate knowledge of what is best in even the most fundamental features, as, for instance, form and dimensions of producer chamber, kind of grate, material for firebrick lining, water cooling of producer walls, size and location of gas flues, manner of air admission, rate of gasification, depth of fire, stationary or revolving ash table, effect of automatic feed, internal or external boilers. In short, it may be said that almost everything in the design is done by traditional methods not based on adequate experimentation and data. Of course, there are three or four different systems solving some of these problems in a fairly satisfactory manner, but there is little scientific knowledge available as to which of these is the most efficient. This is one of the many cases where technical practice goes its own and independent path toward an economic aim, neither aided nor obstructed by scientific knowledge, which can only construe a theory on the basis of experiments made on the new and successful machine after the same has been completed.

34 Some of the above problems have recently been solved to a certain extent for European fuels. Thus it was found advantageous for the lower grades of bituminous coal, to make the producer proper of cast iron with water cooled walls. This eliminates clinkering entirely. The cooling effect of the water does not extend very far internally but only affects the layers located at the extreme outside. The influence on the combustion process proper is, therefore, inconsiderable. Further, with large producers, it has been found that the continuously revolving ash table was wasteful in consumption; too much coal passing through unburnt, and that the agitation disturbed the quiet action of the fire by constantly breaking up the numerous small gas passages in the fuel bed. Finally, it was found advantageous to have some preferably automatic control of the blast or of the suction pressure effecting gasification in order to be able to reduce or to increase the rate according to the condition of the fire or the load on the engine or station. In experimenting on this latter condition, it was found advantageous to insert between gas engine and producer a fan the speed of which is automatically varied according to the

engine or station load. Th incr lasticity of the plant, making the producer a e of carrying heavy and lasting overloads without affecting t gine. At the same time it eliminates spare producer units, g hol lers, pressure regulators, pulsometers, and other cumbersome and pensive apparatus, and keeps the supply of gas steady and of more uniform quality.

35 The possibility of increasing the rate of gasification by means separate from the engine, as by induced draught, should be carefully investigated since it affords the ed means of reducing the cost of equipment at the same time incr g their flexibility. Fortunately, the gas producer possesses in a m ked degree the desirable feature of overload capacity, in which the as engine is lacking.

36 The gas holder is one of t ppliances that can be replaced by superior arrangements. As an ratus for improving the quality and uniformity of the gas by prom ting diffusion and separating out the water molecules, it cannot be r arded as adequate, exposing, as it does, a large volume of gas to the varying and uncertain atmospheric influences of the season. As a sto age tank for meeting fluctuations of load and peak loads of long du ation, its value is problematical unless made very large, especially for the weak power gases. To keep a 500 h.p. engine running for 25 minutes the holder must have a capacity of 20,000 cu. ft. Long gas mains of ample section are a sufficient reserve for equalizing the pressure at short periods of fluctuations. In ordinary suction producer practice it is obvious that the large volume of gas between engine and producer reduces the suction effect of the former and the sharpness of the draught through the fire.

37 For operating gas engines on board ship, producers must have means for keeping up the temperature in the producer while the engine is running at slow speeds or stopping, since otherwise it will not start up again on account of lack of suitable gas. This can be readily obtained by keeping up the rate of gasification through the exhausting fan and returning the gas into the producer where it is consumed again, there being practically no loss but that of the sensible heat of the gas radiating through the piping and, of course, the power required for driving the fan.

38 No producer can be regarded as up to date that does not embody means of automatically adjusting the amount of water or steam admitted together with the air into the fire bed in fixed proportions according to the load, since without this arrangement, the fire will grow dead at the lower loads and the engine will not be able to pull up to a higher load again when necessary.

39 There are a great many questions that are yet unsettled, and

await solution in producer theory and practice and it is gratifying to know that this Society has taken active steps toward thoroughly investigating the matter by a Committee.

40 While the ordinary anthracite and coke producers show a general similarity at least in type, the bituminous coal producers and such as burn lignite and peat, offer a striking variety of forms. We have such taking air in from below the grate, or from its circumference, or from a central pipe, and others having the fire on top and taking air from above. Still others have two fires and take air from both sides. With the double zone producer as developed by Fichet and Heurty in France, and by the Deutz Motor Works and by Koerting Brothers in Germany, lignite and peat is the most desirable fuel to

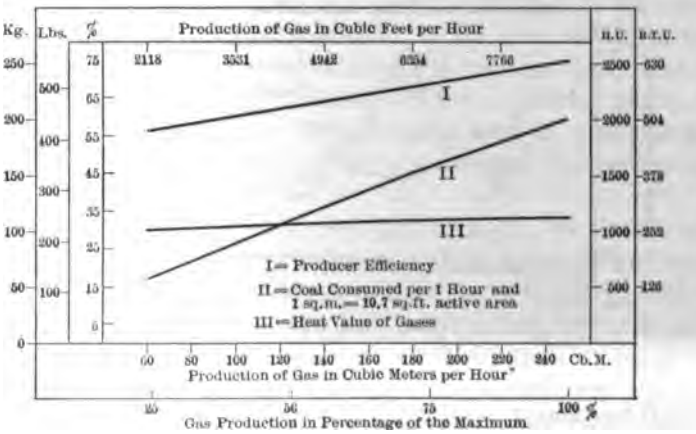

FIG. 6 PERFORMANCE OF DEUTZ DOUBLE ZONE LIGNITE PRODUCER

use, especially in form of briquettes. The raw fuels may also be burnt provided that they do not contain over 20 per cent of water, since otherwise the upper zone of combustion is apt to gradually wander down and therefore a second grate has to be inserted. However, lignite and peat containing excessive moisture are of little importance beyond the field of their production on account of the high cost of transportation.

41 The double combustion process in itself is very simple. In the upper layers the coal is transformed to coke, the unstable gases being discharged through the incandescent zone where they are transformed to fixed gases. The coke thus formed is burnt up in the lower fire after it has been extinguished for some time in the middle zone on its way downward. The gases formed below are, of course, stable and are drawn off together with those from above.

42 While the average consumption of anthracite and coke producers is about one pound per B.h.p. hour and usually less, Fig. 6 shows the performance of a Deutz double zone producer burning lignite as fuel. It is seen that the efficiency of the process drops from 75 per cent at full load to 63 per cent at half load. This is not a very good performance for a producer, generally speaking, since with superior fuels up to 85 per cent efficiency can be attained. But it is of greater importance for the regularity of running that the composition of the gas remains practically constant at all loads as is indicated by the curve. The economic results of these plants are excellent. An 80 h.p. plant using Bohemian lignite of 9200 B.t.u. lbs. consumed on test 1.19 lbs. per h.p. hour, corresponding to a heat consumption of

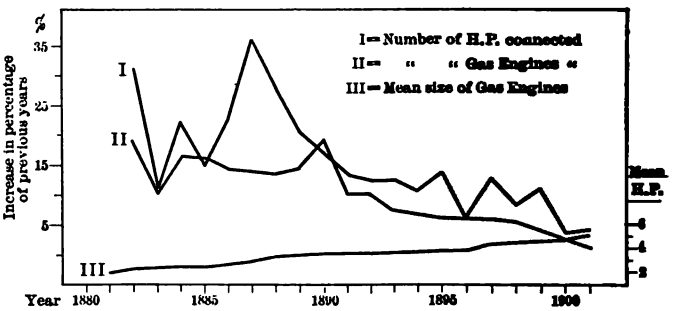

FIG. 7 TABLE SHOWING INCREASING APPLICATION OF GAS POWER FROM ILLUMINATING GAS IN 200 CITIES (GERMANY)

1100 B.t.u., and to a price of one-eighth of a cent per h.p. hour in the particular location. (Meissen.)

43 It is, of course, impossible to state cost prices of such fuels as are adaptable to this type of producer and to consider them as correct and acceptable everywhere, since conditions of production and transportation must necessarily differ in different localities. To give an approximate idea of what obtains in the greater part of Germany, where in the neighborhood of 7000 h.p. are generated in lignite producers alone, it may be said that 50,000,000 tons of lignite were produced in 1905 and it seems that the stability of inland production will continue for a long time to come, disregarding entirely the importation of Bohemian coals. Since the price of average good gas coke is about three times higher than that of lignite briquettes, its heating value being only about 1½ times higher, the cost per unit power in producer gas engines is from 40 to 50 per cent lower when using lignite briquettes than when burning coke. The difference may be even greater in certain localities depending on the respective freight charges. We only

need to glance at the map published by the U. S. Geological Survey,[1] showing the distribution of lignite and peat fuels in this country, in order to become aware of the impending revolution in power producing methods and of the influence and the changes which it must have in the development of certain remote districts, notably in Dakota, Wyoming and Texas.

44 The successful gasification of other low grade combustibles, such as culm banks, is performed among others in the Jahns ring producer. It consists of a series of retort chambers containing the incandescent charge at different stages of the transformation process. Through these chambers the gas is drawn in succession. After the contents of one chamber have been completely gasified, it is separated from the rest, emptied, cleaned, and charged up again to afterward enter the ring as the youngest member. In the Von der Heydt coal mine at Saarbruecken, Germany, 2100 tons of culm are being gasified per month, giving out a total of 40,000,000 B.t.u.; in other words, 2.2 pounds of this waste generate 7140 B.t.u. in form of available gas. The gas is used for driving gas engines and the plant has been in successful operation since 1903.[2]

45 Coming now to the third part of the subject, we shall briefly consider the application of gas power in modern industrial and other pursuits. Of all the various industries which have been benefited by the evolution of gas power, the iron industry has been the most favored, since the blast furnace as the potential source of energy not only serves to convert the raw materials into pig iron, but also produces gas as a valuable by-product. This can be used for producing the power that is required in the power plant proper, and besides leaves available a considerable surplus for other uses.

46 It is a well known fact which need not be here developed in detail that of the total quantity of gas generated in a blast furnace plant about 50 per cent is required within the plant. This includes losses at the furnace top and in pipings, viz: for driving blowing engines, heating blast stoves, operating the cleaning plant, and generating electric energy in the central station, while the rest, representing an amount equal to 25 h.p. per ton of pig iron produced every 24 hours is available for outside purposes or sale. Modern combined

[1]Report of the operations of the Coal Testing Plant of the United States Geological Survey at the St. Louis Exposition, Part I. Field Work, Classification of Coals, Chemical Works.

[2]For detailed information reference may be had to Samuel S. Weyer's "Producer Gas and Gas Producers." Also Mathots' "Modern Engines and Producers," and to Sexton's "Producer Gas."

works often possess their own col ... n plants, which represent an additional source of available power.

47 In modern by-product o ... s the quantity of gas produced depends on the quality of the c ... coked, on its moisture and on the type of oven, and varies co ... ly in composition during one coking period. Deducting 60 per cent for heating retorts and 10 per cent for driving plant auxiliaries, there remain available for every ton of coal coked in 24 hours, from 5 to 6 h.p. for other uses. The third source of energy previously referred to, namely, the gasification of culm piles, will liberate from every ton of culm charged in the producer in 24 hours about 25 h.p., af ... deducting losses through deterioration, etc.[1]

48 That the total amount of useful power that can be gained by scientific transformation from the first two sources alone is no negligible quantity, will be seen when applying the above figures to American conditions. With an annual coke production of 35,000,000 tons in the United States, and utilization of the coke oven gases in regenerative ovens, there can be liberated with modern gas engines in the neighborhood of 1,500,000 h.p., if a best co ... umption of 8000 B.t.u. per brake horse power is assumed. With an annual pig iron production of 25,000,000 tons the surplus blast furnace gases will generate in the neighborhood of 3,000,000 h.p. in gas engines.

49 This large amount of surplus energy can, of course, be liberated only when gas power is employed for driving all machinery within the works. In small countries like Germany, England, and Belgium, the disposal of the available energy from iron smelting plants and coal mines offers no difficulty, owing to the close concentration of industrial centers. The power is partly used for electric distribution to other works or mines which have no individual power plant of their own but only possess transformer substations. Part of the energy is sent to neighboring cities for lighting and other purposes. In the majority of cases it is found advantageous to distribute the surplus energy in the form of electric current rather than as gas, though this practice cannot be generalized.

[1]It has been found that the gain which can be effected from either the sensible heat of the gases in steam boilers, or from their sensible and their inherent heat, or from the combustion of all surplus gases in gas engines is approximately the same in the three types of coke ovens, *i. e.*, the beehive, the by-product, and the regenerative oven. In the latest regenerative ovens of the Otto type up to 140 cbm. (4940 cu. ft.) of gas per ton of coal coked are attained, the gas consisting chiefly of CH_4 and H, and having a calorific value of about 4000 calories per cubic meter (448 B.t.u. per cu. ft.).

50 A third application which the surplus power has found in Germany, and which recommends itself for adoption especially in this country, is to drive electric railways for the transportation of raw materials and finished goods throughout the commercial distribution sphere of iron and steel works. It is obviously better for the iron masters to get control of the transportation factor by building and driving their own railroads independent of the railroad companies.[1]

51 Technically considered, this problem is very attractive, since the particular application affords a nearly constant outlet for the surplus power all year round, because the production of iron and the consumption of energy are balancing each other. When depending on unstable outside markets, we always have to introduce into the calculation a coefficient of safety. With two blast furnaces, we can only figure on the available surplus power of one furnace as forming the basis for a guarantee to an outside consumer, since a fluctuation in the iron market may require the banking of one furnace. Also the plant load factor of the proposed application becomes higher than when current is supplied to a neighboring city for lighting purposes.

52 In Germany it was planned some time ago to build a high-speed electric railway from Berlin to Vienna and to use the various iron smelting plants and collieries located along the road as substations for supplying electric energy to the line. But it was found that there was in most cases an adequate consumption of surplus power in the neighboring districts of these plants, so that there was not enough energy left available for realizing this project. In this country there are in certain localities vastly greater possibilities for operation in the direction indicated.

53 We cannot leave this part of the subject without laying particular emphasis on the fact that the gases must be cooled, cleaned, and dried before being used for the production of power in gas engines. With blast furnace gas the dust and the moisture must be eliminated not only when the gas is used in gas engines but also, though to a less degree, when it is burnt under boilers or used for heating blast stoves, etc., since plant economy is thereby greatly increased. The cleaning apparatus giving highest all around efficiency are the centrifugal high-speed type, such as the ordinary fan and the Theissen washer. The power expended in cleaning the gas can be brought

[1] In one case where 34 per cent of the value of iron ores was formerly paid to the government for transportation charges, the independent railroad owned by the steel works has effected a reduction of this item to one-half. In other cases the saving effected was 20 cents per ton of ore delivered. These figures do not include the saving effected by the utilization of the waste gases.

down to from 2.5 to 1 per cent of the power obtained by the purified gas. The consumption of water varies from six to nine gallons per 1000 cu. ft.[1]

54 It is difficult to obtain correct figures on the total savings that can be effected in the production of iron by the application of gas power, but from 50 cents to $1 per ton of pig iron made have been recorded in various continental works, and from $3 to $4 per ton of finished goods turned out.

55 In central electric stations which are located where no energy is available from near-by iron smelting plants or coal mines, the gas producer takes the place of the blast furnace and coke oven as the potential source of energy. Especially is the production of electric power at reasonable rates of importance for very large cities where the price of real estate in the centers of districts is high, and for isolated communities, country houses, and farms which are located outside the commercial radius of metropolitan or other central stations. The distribution of town gas for individual power purposes, while not so much restricted to central location within the city cannot, without loss, be extended over wide territories. Moreover, at the present price of illuminating gas, it cannot compete in the field of power production with the independent suction gas plant even if the latter use such high grade fuels as anthracite and coke.

56 Suction plants will work in the smallest sizes as economically as in the larger, and, of course, vastly more so than the largest and best equipped steam plants. They occupy very little space and may be installed in the basement of apartment and other houses without being at all dangerous or difficult to handle. Naturally the attendant must possess a degree of intelligence and training similar to one running a steam engine, though beside removing the ashes once a day his occupation only consists in filling the hopper with fresh fuel once or twice every two hours. The rest of the plant is self-regulating and needs no attention. Starting from cold does not require more than from ten to fifteen minutes. The smoke nuisance which is sometimes so objectionable in cities, is completely eliminated for all grades of coal that can be gasified. The personal equation is greatly reduced, since the process of gasification is not dependent on the skill of the fireman. Stand by losses are also very low compared to steam plants. For small work and very intermittent working oil and alcohol

[1]For detailed information reference may be had to author's articles on "Gas Power Economics," and on "The Cleaning of Blast Furnace Gas," published in "Iron Age," April, May, and September, 1906.

engines are superior, since with them fuel consumption stops entirely as soon as the engine is shut down.

57 Speaking more particularly of the generation of power from illuminating gas, Fig. 7 shows the increase of the number of h.p. delivered from city gas works, of the number of illuminating gas engines operated, and of the average capacity of these engines in percentage of the figures obtained each previous year, all data referring to the performances recorded in Germany. During the 20 years for which data are available, the number of illuminating gas engines has increased more than sevenfold, the number of mean h.p. generated having grown in proportion from 1 to 18.

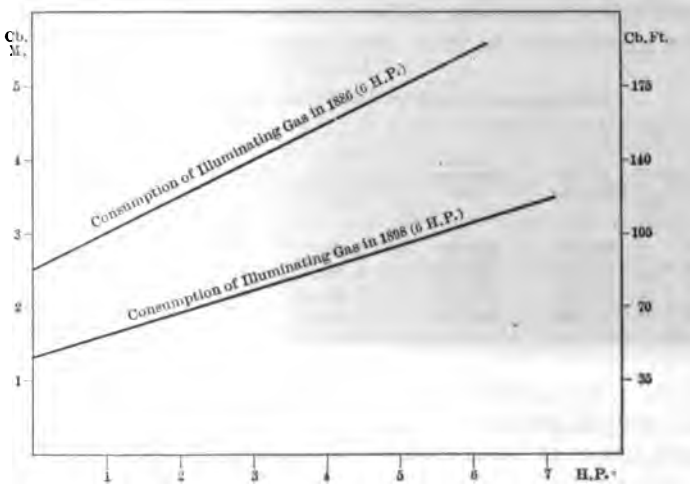

FIG. 8 CONSUMPTION OF KOERTING GAS ENGINE IN 1886 AND 1898

58 The price for town gas has been gradually reduced during this period, the range being represented by the two extreme limits $1.77 and 60 cents per 1000 cu. ft. in 1881 and 1901, respectively. The economy of the illuminating gas engine has in the meantime been increased in a measure represented by curves Fig. 8, which show the comparative consumption of two 6 h.p. Koerting gas engines, of which one was exhibited at the Karlsruhe Exposition in 1886, the other at the exhibition in Munich in 1898. Both tables together show how in the course of evolution the generation of power from city has grown more and more economical.

59 In order to analyze the influence of the electrical industry on the above performances, curves Fig. 9 have been plotted showing the items corresponding to Fig. 7, namely, the increase in the number

of electrical h.p. generated, in the number of electromotors employed, and in the mean capacity of the motors. A careful comparison of all the items bearing on the statistics of both gas and electric power application during the above period in Germany established the following conclusions.

60 A The mean capacity of gas and electromotors operated from central plants has continuously increased.

61 B The annual working time of gas engines compared to that of electromotors bears a ratio of 10 to 4, the amortisation figured on the h.p. hour of both is approximately the same.

62 C The price of current from electric central stations for power purposes has remained practically the same from 1897 to 1901, but the price of illuminating gas for power purposes has been lowered.

TABLE 10

PERFORMANCE OF SUCTION GAS PLANTS IN BERLIN (GERMANY)

BLOCK	KW. HOURS RENDERED	COAL CONSUMED LBS.	COAL CONSUMED PER KW.HOUR LBS.	TOTAL COAL CONSUMPTION LBS.	OIL CONSUMED PER KW.HOUR GRAINS	COAL CONSUMED PER B.H.P. HOUR LBS.
1	370,774	654,597	1.78	7,249	137	1.11
2	273,913	481,708	1.76	4,349	120	1.10
3	273,354	506,722	1.84	3,068	129	1.14
4	183,978	350,020	1.89	2,008	74	1.18

63 D The increase in the number of electromotors connected with public central stations is considerable, while that of the gas engines is small, one of the main reasons being found in the introduction and growing application of the independent suction gas plant. In order that the gas companies may not lose control of the situation entirely they will have to reduce the price for illuminating power gas considerably.

64 E From the data at hand it is impossible to ascribe the fact of the small increase of the number of gas engines connected with city gas works to the influence of the growing central station business.

65 F The price per h.p. hour from gas engines had in 1901 been reduced to about two-fifths of what it was in 1886.

66 A few words may be said on the results attained with independent suction gas producers in the course of the last few years. In the central part of Berlin where real estate prices and electricity supply conditions are very similar to those which obtain in New York, there are quite a number of independent suction gas plants installed serving to deliver electric energy to individual blocks. In Table 10, the

operating results obtained from January, 1904, until April, 1905, in one of these independent block stations are shown. It is seen that the average continuous fuel consumption per kw. hour is about $1\frac{3}{4}$ lbs. of anthracite, corresponding to a price of a little more than half a cent. These results do certainly encourage further efforts towards independence from public central stations. But they may even be improved upon by using lignite briquettes, with which a consumption of only 1.76 lbs. per kw. hour is guaranteed by German manufacturers.

67 Fig. 11 gives a comparison of the cost of power in over 220 towns and districts of England from the three sources, (1) public electricity supply, (2) public gas supply, and (3) own suction gas plant. It is seen that the number of places where the respective cost lines would cross or superimpose each other is exceedingly small,

TABLE 12

PERFORMANCE OF SUCTION GAS DRIVEN PUMPING PLANTS (ENGLAND)

LOCATION OF PLANT	PUMP H. P.	HEAD IN FT.	COAL PER H. P. HOUR LBS.	
Welwyn Water Works	1.896	120	2.17	
Paris-Plage "	13.9	137.6	1.68	
East Kent "	13.64	255	1.3	coke
	12.96	330	1.28	coke

which means that in ninety-nine cases out of a hundred, it is more economical to install independent suction gas power instead of using city gas engines or electric motors, the amount of saving being represented by the ordinate distance of the respective curves.

68 In metropolitan and other pumping stations suction gas power has been adopted with great success, the duty per pound of lignite briquettes being 1,270,000 foot pounds in Germany. Table 12 shows the results attained with some of such plants in England.

69 The application of gas power by means of the portable gasolene engine on such farms where the cheapest forms of producing motion, viz: wind or water, are either not available or unreliable, and where steam power is too expensive and electrical energy cannot be had, has filled a long felt want. On the continent this form has been superseded by the alcohol motor, which is now to become a claimant for recognition also in this country. It would take too long to enumerate here the many farm machines which can now be operated by the adoption of gas power, accomplishing such operations as have made farm work drudgery for years. The stockman, the fruit grower

the thresher, the mill owner, will readily testify to the comforts and savings which the evolution of this new power has bestowed upon them. Yet we are only at the beginning of the new era. Just now the portable suction gas plant is coming into practical use in Germany, enabling the farmer, instead of buying expensive gasolene or converting potatoes or other valuable matter by a costly process into fuel alcohol, to take the straw or hay saw mill refuse, or other vegetable matter growing on the farm, and feed it directly to the producer to be there gasified, generating the required power at no additional heat cost. In order to get the same rk output with straw about four times the weight of coal and 40 nes its volume must be burnt.[1]

70 In sugar plantations, enormous savings can be effected by burning the bagasse in gas produ ers instead of under boilers. In

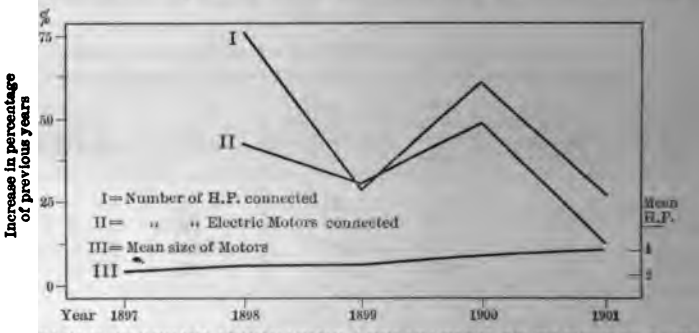

FIG. 9 TABLE SHOWING INCREASING APPLICATION OF ELECTRIC POWER FROM CENTRAL STATIONS IN 100 CITIES (GERMANY)

some cases, where additional steam coal has to be transported from considerable distances, this item of expense may be eliminated entirely by the application of gas power, since it gives from three to four times as much energy from the available fuel as a steam engine plant.

71 It is difficult to obtain similar data to the above in this country, since the number of suction gas plants in actual operation is too small

[1]In a 70 h.p. plant a h.p. hour was obtained with only 2.31 lbs. of straw and a little less of hay. Allowing in this particular case, per h.p. hour, the sum of one cent for operating expenses and interest, and a value of $4.40 per ton for straw, it was found that a h. p. hour cost 1.26 cents with wheat straw and 1.14 cents with oat straw. With the best portable steam engines coal gives the h.p. hour for 4 cents, and petrol gives about the same, while electric motors run from a distant hydraulic plant cost in the neighborhood from 12 cents to 16 cents per h.p. hour. Where the straw has no immediate value and is burned, as is the case on some American farms in the West, the application of this form of gas power generation is, of course, even more profitable.

to allow us to arrive at just conclusions as to their relative cost and fitness for competition with other forms of power generation. Conditions differ from those which obtain in Europe, in that there is even a greater variety of prices for the different grades of coal in different localities.

Further, we have in some districts, where natural gas of 1000 B.t.u. is available, a fuel which makes every other form of power production from coal practically non-competitive. But natural gas is a declining factor on which no definite claims for future activities can be based. Nor is it available everywhere, while the present enormous output of 393,000,000 net tons of coal can be maintained for an infinitely longer time.

72 A comparison of the respective cost of power from city gas on the one hand and from suction gas on the other, is even more strictly dependent on local coal prices. It is also greatly influenced by the class of service, size of engine, load factor, etc. Competition is more difficult for the gas companies, the larger the capacity and the higher the continuous load on the plants.[1]

73 It is impossible to here enter upon any sweeping statement as to what will be the probable issue of the struggle between the large gas undertakings and the consumers of power gas. Their interests are identical in that both expect to get some concession from the capital invested. This much is certain that the gas companies will have to yield to the request of continuous users for a rebate by supplying at the lowest commercial profit, otherwise the user will transfer his custom to the independent plant and the gas companies will forfeit the business. The only question still allowing of discussion is whether, even at the lowest commercial price, illuminating gas will ever rival suction gas for producing motive power, except for very intermittent loads, because suction gas besides being so much cheaper, is, if anything, better for the purpose than city gas.[2]

[1]It has been estimated that if we allow $2500 as total cost of 100 h.p. producer erected; three hours labor per day required by the producer; the engine operating ten hours a day, 300 days per year; interest, depreciation and taxes 15 per cent; engine requiring 12,000 B.t.u. on full load; then in a town where 13,000 B.t.u. anthracite coal may be bought for $6 per ton, the 600 B.t.u. gas must be sold at 27½ cents per 1000 cubic feet to meet the competition of 100 h.p. producer plant when the engine carried full load 10 hours per day and 300 days per year.

[2]Attention is called to an interesting project prepared by Mr. B. H. Thwaite, and submitted to the Parliamentary Committee on the London County Council Electric Supply Bill. The proposal was to use a current of 60,000 volts and to bring it into London over a distance of 120 miles from the coal fields. To generate the electricity it was proposed to use gas engines driven by producer gas. It was

74 As it is likely that the development of power producing and distribution in the more densely populated districts of this country will sooner or later take a course similar to that which it has taken in corresponding sections of Germany, we may expect to see an exchange of energy among the various manufacturing institutions in iron and coal producing fields. Those places where coal is cheap, or waste gases, etc., are available, but which have no market for disposing of the power, will transmit their surplus energy to industrial centers, from whence it will be distributed for further use.

75 The Rhenish-Westphalian Central Station buys power from various collieries and other cheap producers, who are glad to get rid of their surplus energy at a constant profit. A combination of this kind is especially advantageous for the small power producer, since beside running his engines all the time at the highest possible load factor, he need not install spare units. In case of a break down he is entitled by agreement to take, for his individual purposes, energy from the line. Perhaps, if this policy of reciprocal exchange could be extended further, it might help solve the question of competition between the large central stations and gas companies on the one hand and the small independent power producer on the other. If the growing business of the large power companies instead of being met by an enlargement of their existing plants (which is often very difficult and expensive especially in large cities where real estate is high) could be amplified by the delivery of additional energy from smaller independent producers, then both parties could sell power at a profit. The

proposed to use cheapslack and the cost per ton would be only two-fifths of the cost of the fuel used by London electric generators, taking average prices. The sale of by-products would realize 2s. 6d. per ton. The land on which the generating station would be erected would be cheaper, and the saving in rates on about 100,000 kw. capacity would be about 15,000 a year, or about 9s. a year per kw., or .033d. per unit sold.

Another plan proposed by Mr. Arthur J. Martin provides for the distribution of gas under pressure as the means of conveying power from the coal fields in South Yorkshire to London. The scheme involves a transmission pipe line of over 173 miles, the gas being compressed to 500 lbs. per sq. in. At this pressure, 40,000 millions of cubic feet, which is the yearly consumption of gas in greater London, could be conveyed by a single line of pipes 25 inches in diameter. The horse power required to compress the gas would be as much as 40,000 and the cost of the pipe laying, including all incidental expenses, would be roughly, (£) 1,500,000. The annual cost of compression and transmission, including interest and depreciation, works out at 1½d. per 1000 feet, and it is estimated from these and other figures that gas could be delivered in bulk to the existing companies at 7½d. per 1000 cubic feet, and would thus enable them to retail it at a figure which they cannot now approach.

small producer, whose plant may be located near the central station and who can generate gas power with as high thermal efficiency as the largest plant, would find a constant market for his surplus power, while the central station with its established business can sell this power at a higher rate, without having to install additional units and reserves, which soon depreciate without bringing adequate returns. Of course, the larger the number of independent contributors and the smaller the amount of their specific contributions, the more difficult will be the satisfactory organization of a combination of this kind, the difficulties being less of a technical than of an administrative nature.

76 Reference has already been made to the application of gas power for the propulsion of vessels. Ships equipped with suction producers and engines have actually effected a reduction of coal con-

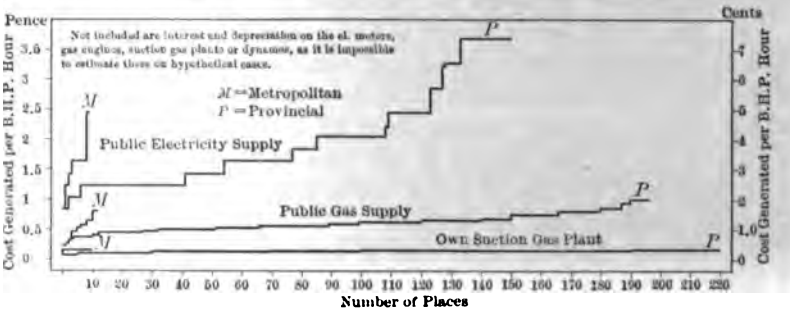

FIG. 11 DESIGN SHOWING COST OF POWER IN 222 TOWNS AND DISTRICTS (ENGLAND)

sumption to one-third of that of steam ships. This fact together with the reduction in space occupied by engines and coal bunkers, and the corresponding gain in cargo space, and the elimination of smoke and smell, make the adoption of gas power of the greatest importance for vessels which are to possess the maximum radius of action combined with the minimum cost of operation. Therefore, builders and owners of canal barges, tug boats, yachts, etc., ought to devote their most careful attention to this new development

77 While there is little or no gain to be expected in bulk and weight of the engine power, the gas producer only occupies about one-third of the space of a water tube boiler, or one-eighth of that of a Scotch marine boiler, the dimensions depending on the grade of coal burned. In a 7000 ton cargo steamer fitted with gas power, the saving in cargo space effected was 13,000 cu.ft. The weight of a gas producer compared to that of a water filled boiler of the type such as

is installed in yachts and tug boats, is from one-fourth to one-fifth that of the latter. The amount of water needed for evaporation is about one-half pound per h. p. for a coal consumption of three-fourths pound.

78 On a trial run a 70 h.p. gas tug consumed in ten hours 530 pounds of German anthracite against 1820 pounds of steam coal used by the competing 75 h.p. steam tug. This economy so far affected is in the ratio 1 to 3.44 and is certainly encouraging enough to induce capitalists and engineers in this country to investigate this matter before foreign practise is getting too far ahead. For the propulsion of larger vessels, the double acting vertical two-cycle engine is the most promising type to be adopted, since it gives steady and quiet motion with variable speed, quick starting under load, and almost instant reverse when compressed air is employed, such features being the indispensable requisites for successful operation on board ship.

79 The Deutz Motor Works of Cologne, Germany, who were the first to investigate the technical and commercial possibilities of gas ships, have fitted their suction gas system on eleven vessels, the power of the various engines ranging from 35 to 90 h.p. Recently they built two flat bottom barges of 240 tons for river traffic, equipped with engines of 100 h.p. of which one is doing active service between Cologne, Antwerp, and Rotterdam.[1]

80 During the year 5200 tons of load were carried representing 1,950,000 ton miles, which was done at a cost of about 25 cents per ton. Had the material been transported from Cologne to Rotterdam by the ordinary steamboats the tariff for transport would have

[1] The total distance traveled is 187½ miles and the time occupied on the round trip, including all stops, with an average load of 200 tons, occupies 14 days, giving an average daily run of 27½ miles under all conditions, thereby enabling 26 round journeys per year to be accomplished. The cost of the vessel was approximately $11,250 and the annual expense of operation, maintenance, etc., work out as follows:

Depreciation on hull, 5 per cent on $5000	$250.00
Depreciation on engines, 10 per cent on $6250	625.00
Interest on capital, 5 per cent on $11,250	561.50
Insurance	11.25
Navigation dues, 26 round trips	975.00
Fuel anthracite at $5 ton; burned at the rate of 1.32 lbs. per h.p. hour for 75 hours per round trip, 50 hours up-stream and 25 hours down-stream, 117 tons	585.00
Lubricating oil, etc.	243.75
Wages	1,750.00
Total annual outlay	$5,002.50

been about 50 per cent higher, while the lowest rate by the railroad would have been five times as much. Another barge of the same capacity is used for the haulage of goods on the Saarbruecken-Muehlhausen Canal, making a round trip of 170 miles which occupies 30 days, including 9 days detention and 9 days with light load. Under these disadvantageous conditions the cost of transportation by the suction gas propelled craft is 33 per cent lower than that of horse traction, while the boat during the year makes eleven round trips as compared with seven complete journeys, which were possible by animal traction before the introduction of the new system.

81 In England, the firm of Thornycroft & Co. have recently built a gas barge which is equipped with a gas plant designed by Herr Capitain, a German engineer who has been very successful along these lines. The barge in question has just completed a trial run over 600 miles in open water. Assuming that the coal used is costing $6 per ton, and that the barge is carrying a net load of 20 tons and traveling at a rate of 6 miles an hour, the cost per hour for fuel is less than 10 cents, if a consumption of 1.2 lbs. per B.h.p. is allowed.

82 In a recent address, delivered by Professor Riedler-Charlottenburg to the *Verein Deutscher Ingenieure* on the evolution of the steam turbine, the situation was characterized by the following remarkable words: "A development of unprecedented rapidity of one of the most difficult motors in the history of mechanical engineering; a sweeping victory in the power station field: a momentous advance of the highest importance, principally to electrical engineering." If we consider that what was thus described is a new machine which transforms the energy of steam into useful power at a higher degree of mechanical excellence, with a saving in weight and bulk and cost of the prime mover and generator, and with a greater uniformity of turning effort, but with the same low economic efficiency, we are at a loss to give expression to the extreme importance which the evolution of gas power possesses as a factor in the field of industrial economics. It may suffice to draw attention to the fact that this is not the substitution, by a rotary type of prime mover, of a reciprocating engine of the same thermal characteristics, but the complete abandonment of a traditional and wasteful process of energy generation in favor of a direct and efficient method. It has not only extended the capacity of our fuel resources to double and more of their former value, but has also enabled us to profitably utilize material and property which was deemed utterly worthless even a few years ago.

83 We need not point out to those upon whom the technical

responsibilities of this particular industry rest how far, by their earnest endeavor, they can help towards the realization of such ideals as are before us. Nor need we dwell on the effect or importance of the scientific study, in our great scholastic centers, of fuel characteristics and conversion as a means for producing proper utilization. It must be patent to all that the more broadcast the dissemination of scientific knowledge of everything that is apt to clarify and amplify our understanding of these commodities, the greater must be the industrial progress.

APPENDIX

84 Referring to Fig. 3, *abcda* represents the ideal diagram of the Otto cycle, at full load. An initial pressure $p_a = 1$ atmosphere, a compression pressure $p_b = 12$ atmospheres, a combustion pressure $p_c = 25$ atmospheres, and a temperature $t_a = 300°$ C. were assumed. Exponent $n = 1.41$, stroke volume $v_s = 200$ mm. scale 1 cm. = 1 atmosphere.

85 On this basis the following data were obtained:

Volume of compression space..... $v_a = 41.44$ mm. (1.63″)
End temperature of compression.. $T_b = 618°$ (1144.4° F.)
End temperature of combustion .. $T_c = 1287°$ (2348.6° F.)
End pressure of expansion ..... $P_d = 2.08$ at. (30.6 lbs sq. in.)
End temperature of expansion.... $T_d = 625°$ (1157° F.)

Hence the thermal efficiency at full load

$$\eta_t = \frac{Q_1 - Q_2}{Q_1} = \frac{T_c - T_d}{T_c} = \frac{T_b - T_a}{T_b} = 51.4 \text{ per cent.}$$

86 Assuming quality regulation and the influx of heat at half load reduced to $\frac{Q_1}{2}$ the following values are obtained: (diagram *abefa*)

End temperature of combustion .. $T_e = 953°$ (1747.4° F.)
End pressure of combustion ..... $P_e = 18.5$ at (272 lbs. per sq. in.)
End pressure of expansion ..... $P_f = 1.54$ at. (22.64 lbs. per sq. in.
End temperature of expansion ... $T_f = 462.5°$ (864.5° F.)
Thermal efficiency ..... $\eta_t = 51.4$ per cent

87 With quantity regulation the influx of heat at half load is again $\frac{Q_1}{2}$ the active stroke volume $\frac{v_h}{2}$, and $T_g = T_a$, and the following values are obtained: (Diagram *ghikag*)

End pressure of compression ..... $P_h = 5.65$ at. (831 lbs. per sq. in.)
End temperature of compression.. $T_h = 496°$ (924.8° F.)
End temperature of combustion .. $T_i = 1068°$ (1954.4° F.)

End pressure of combustion .....P_i = 12.16 at. (178.8 lbs. per sq. in.)
End pressure of expansion .....P_k = 1.012 at. (14.88 lbs. per sq. in.)
End temperature of expansion ...T_k = 518° (964.4° F.)
Exhaust temperature .....T_a = 512° (953.6° F.)
Thermal efficiency .....η_t = 46.8 per cent

88. Referring to Fig. 1, *abcda* represents the ideal diagram of a constant pressure engine at full load. The initial temperature and pressure conditions are assumed to be the same as before. With a stroke volume v_h = 200 mm. the following data are obtained:

Volume of compression space .....v_c = 22.72 mm. (.895″)
End temperature of compression..T_b = 765° (1409° F.)
Volume at end of combustion.....v_3 = 38.22 mm. (1.505″)
End pressure of expansion .....P_d = 2.08 at. (30.57 lbs. per sq. in.)
End temperature of expansion ...T_d = 625° (1157° F).
Thermal efficiency at full load ...η_t = 55.6 per cent

89 At half load the influx of heat is $\frac{Q_1}{2}$, and the following data are obtained: (diagram *abefa*)

End temperature of combustion ..T_e = 1026° (1878° F.)
Volume at end of combustion.....v_4 = 30.46 mm. (1.19″)
End pressure of expansion .....P_f = 1.51 at (22.19 lbs. per sq in.)
End temperature of expansion ...T_f = 454° (849.2° F.)
Thermal efficiency at half load ...η_t = 58 per cent

At no load the total efficiency of the process approaches the thermal efficiency of the elementary process which is expressed by the equation $\eta_t = \frac{T_b - T_a}{T_b}$ = 60.8 per cent

90 Referring back to Fig. 3, diagram *ablmoa* represents the condition of sluggish combustion. Assuming a combustion pressure of p = 14 atmospheres, with continuous combustion at that pressure and the adiabatic compression curve *ab* and the end temperature of compression to be identical, the following data are obtained:

Temperature at point l .....T_l = 721° (1329.8° F.)
Temperature at point m.....T_m = 1124° (2055.2″)
Volume at point m .....v_3 = 64.6 mm. (2.54″)
End temperature of expansion ...T_o = 655° (1211° F.)
Thermal efficiency .....η_t = 47 per cent

91 Under these conditions, which correspond to those of actual practice, the efficiency drops 8.5 per cent below the ideal, while the efficiency of the constant pressure diagram is 18 per cent higher.

92 In Fig. 3 curve *aqrs* represents the condition of premature ignition. Assuming that ignition sets in at a pressure p_q = 2.13 atmospheres the following data are obtained:

Temperature at point q ..... T_q = 373 ( )
Temperature at point r ..... T_r = 1043° (1909.4° F.)
Pressure at point r ..... P_r = 5.93 at. (87.17 lbs. per sq. in.)
Max. pressure at point s ..... P_s = 33.5 at. (492.5 lbs. per sq. in.)

The possibility of such excessive pressures occurring in the working cylinder is a drawback of the Otto cycle which is not inherent in the constant pressure process.

93 An investigation of the relations between the mean effective pressures and the maximum pressures, and between the mean effective pressures of the respective cycles, which is necessary for determining the bore and stroke of the cylinder and the dimensions of the working parts, brings out the following points: With equal maximum pressures and temperatures the mean effective pressure of the constant pressure cycle is 13 per cent higher than that of the Otto cycle. With the latter, an increase of the mean pressure can only be effected by increasing the maximum pressure of combustion; with the former, by prolonging the period of heat influx. Diagram *abtua* represents such an increase with the Otto cycle, corresponding to a mean pressure of 5 atmospheres. The maximum pressure is found to be p_t = 31.5 atmospheres (463.05 lbs. per sq. in.)

The maximum temperature is ..... T_t = 1620° (2948° F.)
The thermal efficiency ..... η_t = 51.3 per cent

94 Diagram *abgha* represents an increased constant pressure diagram, corresponding to a mean pressure of 5 atmospheres (735 lbs per sq. in.)

The maximum pressure ..... P_c = 25 at. (368 lbs. per sq. in.)
The maximum temperature ..... T_g = 1500° (2732° F.)
The thermal efficiency ..... η_t = 54 per cent

A comparison between the two established the following result:

95 For the commerical range equal mean effective pressures are attained in the constant pressure cycle at lower maximum temperatures and pressures and with a higher degree of thermal efficiency than in the Otto cycle.

96 Regarding the relation of the negative work consumed to the positive work rendered, diagram *awba* represents the former and area *awtua* the latter item in the Otto cycle. It is found that the negative work is 29.2 per cent of the positive work.

97 In the constant pressure cycle area *akba* represents the negative and area *akbgha* the positive work, the ratio being 38.4 per cent. It is seen that the negative work expended is smaller in the Otto than it is in the constant pressure cycle.

98 Regarding the influence of prolonged expansion on the economic efficiency of the process, it is found to be unfavorable. By prolonging *gh* down to the atmosphere a diagrammatic area *abghia* is obtained representing a mean pressure of 2.76 atmospheres against 5 atmospheres of the smaller diagram *abgha*. This means that by prolonging expansion the mean effective pressure is reduced to nearly one-half of its value. Hence, to obtain the same capacity with equal stroke, the piston area and, therefore, the maximum piston pressure must be nearly doubled. The increasing thermal efficiency (from 54 per cent to 60.8 per cent) is, therefore, more than counterbalanced by the decreasing mechanical efficiency and by the losses through cooling.

99 Referring to Fig. 2, diagram *abcdea* represents the full load and *ab'c'd'e'a* the half load ideal diagram of a Weidmann continuous combustion engine, while *ghi* and *g'h'i* are the corresponding pump diagrams. The relation of negative pumps work expended to positive work rendered is 6.5 per cent at full load and 8.5 per cent at half load. The thermal efficiency of the process is 49 per cent and 50.2 per cent, respectively.

DISCUSSION

PROF. CHARLES E. LUCKE Mr. Junge's paper has for its subject a rather broad consideration of steam versus gas for power. By gas I mean not necessarily gas fuel, but a perfect gas as a working medium behind the piston distinguished from vapors. He has avoided specifically comparisons of different makes of gas engines, and I rather hope in the discussion of this paper that this topic will not be brought up. Any one, on reading this paper, would be apt to get a high opinion of gas engines for power generation, and, I think, too high an opinion. Gas power, to be worthy of consideration by power plant engineers must be considered in large installations by engines of large size, and should not be discussed for small sizes at all. Large gas engines have peculiarities and troubles not possessed by small engines, and comparison of steam engines and gas engines becomes rather more difficult in the larger sizes than in the smaller ones. I wish, therefore, to examine this question of gas versus steam power, raised by Mr. Junge, and in the light of my presentation to point out a criticism of this paper and perhaps venture on a prediction.

2 I will divide the subject into headings for the examination of the problem:

a "The theoretical possibilities of a perfect gas used in various cycles versus steam used in its best cycles as a method of transforming heat into work." Such examinations on mathematical and thermo-dynamic grounds have been made many times, and they have always proved the superiority of the perfect gas cycle over any steam cycles that can be devised. Therefore, on this point I think I may say without fear of contradiction that the perfect gas cycle is better, and a more efficient means of transforming heat into work than any vapor cycle in which the latent heat necessarily rejected is so high, or in which the difference between total heats at high and low pressures is so small. This would seem to give the gas engine a superior position, and it is along these lines that most of the discussions in print on the superiority of the gas engine are based.

b "The mechanism for carrying out the cycle in a practical machine." On this point I can easily imagine an endless discussion. There are, however, one or two considerations that seem to me more prominent than others, and more important at this time because not generally recognized. The gas engine, in its modern form, that is to say, the form in which it appears in the large sizes, has been through a process of development of only about ten years. We have today large gas engines that will run. Ten years ago we did not. We have not today, however, a specially designed gas engine for each particular set of circumstances under which gas engines have to work. Builders of gas engines have, therefore, taken this single gas engine that would run under certain conditions, not always clearly defined, and have sold it to perform any kind of work under any other conditions, equally indefinite and the engine has frequently failed as a result. We are today just beginning to recognize the importance of adapting the gas engine mechanism to circumstances and conditions, and are still discovering what conditions affect its operation and what do not. When all of these conditions affecting the operation have been discovered and engineers shall have been educated to use this knowledge in designing proper mechanism, then and then only, will we have special gas engines that can fairly compete with steam engines. The steam engine advocates are very

apt to criticise the gas engine advocates and the gas engine advocates are apt to be too sure of the results of the gas engine. This situation is directly a result of either ignorance of the importance of operating conditions and peculiarities of design or a deliberate ignoring of this knowledge, which can only be attained by costly experiments, too costly by far to be ignored.

c "The availability of the fuel." In the early days only gas fuel was burned; later on, vapors of the oils; still later, by-products, such as coke oven gas; and lastly, but most important, gas made from coal in producers. It may be fairly said, therefore, that in the question of the availability of fuel, the steam engine has no position of superiority over the gas engine with the bare possibility of the caking bituminous coal in producers as the one exception.

d "Adaptability of the engine to the work it must do."

e "The skill or cost of the operating labor."

f "The first cost of the machine or plant."

g "Cost of maintenance and repairs."

3 Several other items of a similar nature can be added to this list of points of view from which the comparisons may be made, but all of them hinge upon the one question of "the design of the mechanism of the gas engine" to enable it to do a special service under all conditions imposed. If it should appear that the mechanism can be made as reliable, as cheap, as easily maintained, as adaptable to the work, etc., in the gas engine as in the steam engine, the gas engine would undoubtedly have a superior place. Unfortunately, this has not yet been proved, and the importance of it is not even recognized by some of the gas engine builders. The steam engine has been through such a process of development for many, many years, and it is not yet finished. Ever since the time of James Watt, we as mechanical engineers, have been designing steam engines and are still designing them every day a different one. In other words, we have found it necessary to especially adapt each particular steam engine to the kind of service it has to perform, and to the conditions under which it must work. How different the engines of the locomotive from those of the steam ship, and how different these from the engines of a large central power station. How different are small steam pumps from the large steam pumps, and a hoisting from a pumping engine. How different the high speed steam engine from the slow speed engine; the steam engine using low pressure from that using high pressure steam. We have today no gas engine specially adapted to pump-

ing water; no gas engine fitted for driving ships; no gas engine generally recognized as the one for close regulation; no gas engine specially adapted for mill work, as distinguished from electric generation; no gas engine built specially for long life; no gas engine for power purposes especially distinguished for its small space per horse power, nor one adapted to producer gas as distinguished from blast furnace gas, or to dirty gas as distinguished from clean gas. In short, we have not only not yet designed special gas engines for special conditions, but are only now beginning to realize the necessity for so doing. The failure to recognize the necessity for so doing is the cause of much loss of money and much loss of prestige of the gas engine in the power plant world. I know of only one company building large gas engines, out of a possible list of a dozen or more, that has made any money; practically all of the others have lost money in the business. I know of a great many gas power plants and gas engines that have been rejected for failure to fulfill contract requirements and which have come into the courts for public airing. This loss of money and these failures, together with loss of prestige, and by loss of prestige, business, which is its consequence, are due solely to one thing, and that is ignorance of the limitations of the gas engine mechanism. The builder of the gas engine did not know how to make it particularly adapted to the work. His knowledge was, in many instances, derived from a few experiments in his shops, or, perchance from drawings and information obtained from Europe, the home of the gas engine. At this stage he was probably approached by a purchaser, who had read in the papers of the wonderful performance of the gas engine, the machine that could produce a horse power hour on a pound of coal of any kind, any time and all the time. It was with such an idea as this that the prospective purchaser approached the sales department. The builder, having spent so much money on experimenting, trying to get his machine to run and having finally succeeded in making it run, was faced with the demands of the purchaser for a guarantee of 10,000 B. t. u. per h. p. hr. He may not ever have been able to get as low as 15,000; he may not ever have tested his engine at all because of the cost of large gas meters. He may have been dependent upon the same published reports himself, and in his anxiety to get back his money he gave in to the demands of the purchaser. The engine failed, doing much harm to his business besides the immediate loss of money.

4 Now the point I am making is not that gas engines are going to fail and continue to fail, but that these contracts were made on insufficient information on the part of the builder and unfair demands on

the part of the purchaser, who, knowing nothing of the subject, allowed himself to be controlled by the public press. The purchaser did not know what was fair to demand, except in accordance with what he had read, much of which was false. The builder, either through lack of time, lack of sufficient capital to experiment properly, or indifference, or lack of able designers, or refusal to take the advice of good engineers, did not know what his engine could do, or did not care. When the public shall have been educated to know what it is fair to demand of the gas engine and to recognize what a gas engine can do, and when at the same time, the builders of gas engines shall have recognized the importance of employing the best talent available to design their engines to meet special conditions and shall take the advice of these experts as to the importance of recognizing limiting conditions, then will the gas engine take its place properly beside the steam engine, and not before.

5 Mr. Junge, in his paper, scarcely mentions this point of view, which seems to be so vital to the question. He mentions some high thermal efficiencies, I believe impossibly high ones, but these are of absolutely no use in an engine when at times and under certain circumstances that engine will not run. To the public purchasing gas engines or any other sort of engines for power purposes, I appeal:

a To recognize that the gas engine is, at present, a factor to be considered in every power proposition, and that it is not to be ignored in favor of any steam turbine, steam engine, water power, or other system because, perchance, it is not so familiar;

b To recognize that the gas engine cannot do everything, especially when it is in the one-design form, and that what it can do should best be known to its builders and not to the writers of some magazine article.

c To keep the gas engine builder informed of your special requirements, and invite bids on every power proposition, whether it seems likely they can meet it or not, and in issuing this invitation meet the builder halfway by not imposing utterly ridiculous conditions.

6 To the builders of gas engines I make an appeal as earnest as the one I make to the purchasers of this class of machine:

a Employ the best men on general power plant practice that your money can secure, and consider that man most valuable who, with the above information, also knows the peculiarities of your engine and that of your competitor, with the limitations of both.

b Seek to fill the special needs of purchasers without forcing on the public an engine that any good and competent engineer can plainly see is not adapted to the work.

c Properly experiment for the purpose of determining what modifications of design and detail must be made to meet special service conditions, and when once determined execute them.

d Coöperate with purchasers of gas engines or power plants of any sort by exchanging freely all information on the requirements and performance, and give up at once the hermit like attitude of isolation and secrecy heretofore so common.

MR. R. E. HELLMUND Mr. Junge has brought forward in his paper a series of new possibilities for the utilization of energy which is being lost at present, which decidedly deserve the attention of every engineer. In almost every problem of power utilization, including the methods proposed and cited by Mr. Junge, electricity forms an important factor as means for transmitting the energy from the place of its generation to the place where it is needed. It is obvious, therefore, that the system generating the energy should be well adapted to work in connection with the system of transmission and vice versa.

2 Reviewing the numerous cases mentioned by Mr. Junge, in which a satisfactory combination of energy generation by gas engines and transmission by electricity may lead to considerable advantages, one cannot help but feel sorry, that at the present time the electrical engineer is, as a rule, inclined to avoid the use of a gas engine in his plants as much as possible.

3 At the same time I realize, of course, that these prejudices are not quite without reason. Only about five years ago I found that after gas engines of one of the best makes had been adopted as prime-movers for the direct current power plant of a small German town, much trouble was experienced, because the gas engine (100 k. w.) stopped about once a week in consequence of preignition. Although a battery was provided it was not able to carry the maximum load of the day, and therefore the fuses of the battery blew out and the whole town had to be in the dark for about 10 or 15 minutes. It is obvious that these results are not very apt to influence a power plant engineer to introduce gas engines and unfortunately these early experiences are liable to retard the introduction

of the gas power even when the difficulties mentioned above are practically eliminated.

3 I am pleased to state that the gas engine has been improved so rapidly, during the last five years that there is not the least objection to their use in direct current plants. In alternating current plants some difficulties are still experienced. It is a fact that synchronous alternating current machines, which work perfectly satisfactorily in connection with steam engines, quite frequently cause trouble in consequence of hunting, if they are used in connection with gas engines; this is due to the fact that the angular velocity of gas engines, especially that of smaller units, varies as a rule more than that of steam engines. It must be admitted, however, that in most cases where trouble on account of hunting is experienced, it could have been avoided by the choice of the right make of gas engine and by the choice of the right kind of alternating current machines, *i. e.*, machines with good and effective anti-hunting devices.

4 This is proved by the fact, that quite a number of alternating current plants with gas engines as prime-movers operate very satisfactorily. If power transmissions with gas engines as prime-movers are built, is it necessary that the nature of the gas engine be taken into consideration, when the transmission system is projected. It is, therefore, also advisable, in order to avoid troubles in consequence of hunting, to use motors of the induction type instead of synchronous motors, as is frequently done in case of larger units. Although it is true that the use of induction motors increases the line losses to a certain amount, it should be remembered that in most cases this disadvantage is made up several times by the greater economy of the gas engine compared with the steam engine.

5 If as Mr. Junge suggests in paragraph 75, a number of smaller independent producers furnish energy into the network of a larger central station, it might be even advisable that induction motors driven above synchronism are used as alternators in the plants of the smaller producers, while the main plant is equipped with synchronous alternators.

6 This would have the advantage that the smaller producers would not need to have as high grade men as would otherwise be necessary. Such a system would, of course, only be possible, if the load of the system is always larger than the amount of energy delivered by the smaller consumers into the line.

7 It is beyond any doubt that much can be accomplished along the lines indicated by Mr. Junge, if the engineers building gas

engine plants keep in close touch with electrical engineers and take care to get the apparatus best adapted to work in connection with their plants.

MR. W. D. ENNIS There seems to be divergence of opinion as to the relative costs of the installation of steam and gas power plants. Mr. Junge argues that the higher first cost of the gas plant may be disregarded. An article by Mr. W. Schomburg, in the "Elektrotechnische Zeitschrift" is quoted in a recent number of the "Electrical Age," which gives $112.50 and $135 as the respective costs per kilowatt. This certainly does not correspond to American practice. The Boston Elevated Railroad found the gas plant to be about 75 per cent more expensive. A recent magazine article stated the difference to be 42 per cent. Probably from 50 to 75 per cent is the average difference in this country for plants of equal size, the wide variation being due to the fact that no two people figure alike as to just how much refinement of detail is justifiable. This is a serious handicap for the gas plant.

2 Mr. Junge gives figures representing the best Continental practice. He reports producer efficiencies up to 85 per cent. Schomburg gives 75 to 80 per cent, less 10 per cent for stand-by losses. Mr. Bibbins, in his paper presented at this meeting of the Society, reports a maximum of 71½ per cent. It would not appear, therefore, that we, on this side, have as yet exceeded, if we have equaled, the efficiency of the steam boiler.

3 Neither have we obtained any such thermal efficiency with our gas engine as 38.6 per cent. The best result given in Mr. Bibbin's paper is 1.5 pounds of coal (13,500 B. t. u.) per kilowatt hour. Assuming efficiency of producer and line to have been 70 per cent, of generator and leads 93 per cent, and of engine mechanism 87½ per cent, the thermal efficiency of the engines was 29.6 per cent. The Boston Elevated Railroad reported a 30 day run on 1.31 pounds of coal per kilowatt hour. Assuming 14,200 B. t. u. in the coal (Pocahontas), and efficiencies as before, the thermal efficiency of the engines was 32.2 per cent.

4 If we accept 38.6 per cent as the best as yet obtainable with gas, what is the outlook for the steam engine?

5 Professor Hood, in his paper on the new record breaking steam engine performance, presented at this present meeting, quotes an efficiency, as compared with the Carnot cycle for the conditions, of 73.69 per cent. To equal the gas engine standard, assuming that we cannot increase this figure, we must work in a Carnot cycle having

an efficiency of $38.6 \div .7369 = 52.4$ per cent. At the present time, our best practicable vacuum is 28 inches, corresponding to a temperature of 100 degrees. With this as the lower temperature of our cycle we must, in order to secure an efficiency of 0.524, employ steam at an initial temperature slightly over 700 degrees. Temperatures higher than this were observed by Professor Carpenter, according to his paper on the White motor car engine.

6 We have therefore obtained in two separate trials, two results, which, if secured concurrently, would give us an efficiency equal to the best as yet claimed for the gas engine.

7 There is one important point in connection with these record breaking figures. Professor Hood's engine shows a thermal efficiency of 25.1 per cent. It may be a long struggle from this point to the 38.6 per cent of the gas engine; no doubt it will be a struggle for other gas engines as well as for the steam engine. But the practical desideratum is to work up to these efficiencies, rather than to work up beyond them. With the vast majority of our engines, even in good plants, having a thermal efficiency not over 10 or 12 per cent, there is a possibility of a gain of 100 per cent by reaching Professor Hood's figures; beyond that, even up to the gas engine record, the possible gain is only 50 per cent. What we need, in both boiler and engine practice, is not so much new record breaking efficiencies as a nearer approach to these efficiencies in ordinary plant operation; and this is getting to be more and more a matter of load factor, so far as the engines are concerned; and of air supply regulation, in boiler operation.

PROF. R. C. CARPENTER The paper by Mr. Junge is a valuable one for the reason that it calls attention in a brief and concise manner to the principal epochs in the development of the internal combustion engine and to the characteristics and advantages of the various working cycles which have been invented from time to time.

2 The reference to the work by the American inventor and engineer, Mr. George B. Brayton, should not be without interest to The American Society of Mechanical Engineers; due to the fact that the cycle which he invented possesses theoretical and practical advantages over the Otto and has essentially the same characteristics in practical operation as that of the Diesel which differs, however, theoretically, and was invented much later. The Brayton cycle is one in which ignition takes place at constant pressure, whereas the theoretical Diesel cycle, as described in his patent,

is one in which ignition takes place at constant temperature; practically, however, the Diesel engine more often operates on the constant pressure or Brayton cycle than on the constant temperature or Diesel cycle.

3 In connection with the suit brought for infringement of the Selden patent for use of a gas engine on a motor car, a thorough investigation has been made of the work done by Mr. George B. Brayton in developing his internal combustion motor, which proves that Mr. Brayton occupied a position, both theoretically and practically, much in advance of his time. As his life and work must be of great interest to American mechanical engineers, I will call attention briefly to some of the work which he accomplished.

4 Mr. Brayton was granted four patents for his internal combustion engines. The first, dated in 1872, was for a gas engine, in which the gas and air were drawn by suction into an air compressor in proper proportions for a combustible mixture and were there compressed to the desired pressure and delivered into a reservoir, from this reservoir the combustible mixture was fed into the working cylinder where it was ignited. A cut-off valve controlled by a governor shut off the supply at the proper time to produce uniform speed. A concontinuous flame was maintained in the working cylinder which was fed from the reservoir through a small opening. The constant pressure gas engine of Brayton's was used quite extensively and a test was made by Dr. R. H. Thurston which is published in the report of the Vienna Exposition of 1873. This engine proved to be troublesome to maintain, principally due to the difficulty of preventing the flame passing back from the working cylinder into the reservoir filled with combustible mixture of gas and air and causing an explosion. Because of this difficulty Brayton was led to design a new engine in which oil was the source of fuel instead of gas, which was patented in 1874. It operated in much the same manner as the engine of the 1872 patent, but the air compressor was used for the purpose of compressing air only and the oil was injected by a special pump directly into a vaporizing chamber which was closely connected and an essential part of the working cylinder.

5 The Brayton oil or hydro-carbon engine was built by several firms in this country, each of which was given a limited territory to supply. Several hundred motors were made and were used for a great variety of purposes. The engines designed for stationary purposes were generally built with an inverted walking beam arranged to connect the working cylinder and the air compression cylinder. These engines were exhibited at the Centennial Exhi-

bition in 1876, pumping water and driving machinery. One of these engines, of 3 h.p., was used by Dr. Draper in his investigations of the properties of light in 1877–8, and is still in existence and is owned by the complainants in the Selden patent case referred to above.

6 Another engine of 5 h.p. was used by Prof. Anthony in 1875 in a lecture before the Cooper Union, to drive the first dynamo machine, of the Gramme type, ever built in America. This latter machine was afterwards bought by Cornell University and was used by that institution for several years for furnishing the power for the Physical Laboratory. It is still in good working condition and forms a part of the equipment of the Mechanical Laboratory of Sibley College.

7 The Brayton engines in operation were comparatively noiseless and gave an indicator diagram much like that from the Corliss engine. Brayton considered these engines as "combustion" engines rather than "explosion" engines because of the smoothness of their operation, which was due to the peculiar character of the combustion. The Brayton engine was designed to operate at the maximum pressure of 60 to 80 pounds, and for these conditions its economy was very poor, being much inferior to that of the unmechanical free piston engine which was built by Otto and Langen. The actual efficiency on the basis of heat converted into work, in accordance with Clerk, was seven per cent when gas was used and six per cent when oil was used, the low efficiency being very largely due to low pressures, to friction, and losses between the air compressor and working cylinder. The efficiency of the Otto-Langen engine was from 50 to 100 per cent better than that of the Lenoir engine only about one-half as great.

8 There is abundant evidence to prove that Brayton constructed his engines in numerous forms, as for instance, double acting engines with separate compression cylinder; single acting engines with the combustion chamber in one end and the compression pump in the other, walking beam engines, the cylinders in some cases above and in other cases below the walking beam.

9 The engines were applied for the propulsion of boats and were used commercially for this purpose. They were also applied for the purpose of propelling a street car and operating a bus. No commercial success attended the application to the street car or to the bus.

10 The early engines of Brayton were of the two cycle class. In 1890 he patented an engine of the four cycle type of which a limited number were built. A test of one of these engines was

made by Mr. Dugald Clerk which shows great superiority of the early type.

11 Mr. Brayton died in 1893. The above concise statement of his work indicates that he is entitled to a prominent place in the development of the gas engine and recent investigations indicate that his cycle is likely to be extensively used in the future. I hope that a full description of his life and machines will be presented to the Society at some future meeting.

PROF. H. DIEDERICHS The presentation of the subject, in general, is so complete that little can be added. The great importance of the gas power question is conceded, and the recent placing of large orders for Loomis-Pettibone producers with the Power and Mining Machinery Co., and for Allis-Chalmers blowing engines by the Carnegie Steel Co., would seem to show that our own power users have not only considered, but have already very largely decided the question for themselves.

2 The writer is in thorough accord with the statements made regarding the Brayton, now the so-called Diesel cycle, the possibilities of the constant pressure gas engine having up to this time not been fully realized. It is true that Diesel carried the oil engine, working on this principle to a degree of perfection never before attained, but the oil engine is limited in its capacity owing to the difficulty of satisfactory combustion in large cylinders. The constant pressure gas engine has never been developed to the extent that the promise of its cycle seems to warrant. Of course, it is realized that there are serious difficulties connected with the handling of comparatively large bodies of gas under high pressures, but producer gas, and not oil, will be the fuel of importance and hence the constant pressure gas engine seems worthy of a little more attention than it has so far received.

3 The computations made by Mr. Junge on type cycles in the appendix of the paper are of interest and show in a limited way the relation between the constant volume, or Otto, and the constant pressure, or Brayton, cycle for the conditions assumed. To get a clear insight into this relation for himself, the writer in 1904 constructed a three-dimension diagram, published in the Sibley Journal, which may prove of interest.

4 It can be shown that the efficiency of the ideal Otto cycle is in general

$$E = 1 - \frac{1}{r^{n-1}}$$

and that of the constant pressure cycle is

$$E_1 = 1 - \frac{1}{r_1^{\,n-2}} \qquad \frac{(d^n - 1)}{n(d - 1)}$$

5 In these equations, r or r_1 = compression ratio

$$= \frac{\text{stroke volume} + \text{clearance volume}}{\text{clearance volume}}$$

n = exponent in the equation $pv^n = \text{const.}$ for the compression line.

and d = cut-off ratio in the constant pressure cycle

$$= \frac{\text{volume at cut-off}}{\text{clearance volume.}}$$

6 Now it is evident from an inspection of the two equations that for the same values of r and n, that is, for the same compression pressure, E will always be greater than E_1. But in practice the operating limit is not due to the compression pressure but to the maximum pressure occurring in the cycle. It then becomes interesting to see what the conditions are when maximum pressures are assumed equal in the two cycles.

7 To obtain a basis of comparison the following assumptions were made:

a The maximum pressure in each cycle is 25 atm. (352 pounds per square inch.)

b Value of $n = 1.37$, an average figure.

c Each cycle is assumed to receive the same quantity of heat, *i. e.*, that necessary for the nominal horse power under the conditions chosen.

d The temperature at the beginning of compression is assumed at 600 degrees Fahr. absolute.

8 The diagram, herewith, shows the result of these computations. Efficiencies are plotted from bottom to top. From right to left are given values of d, and from front to back values of r or r^1. In this case r stands for the ratio of compression in the constant pressure cycle, while r^1 represents the equivalent ratio of compression required in the constant volume cycle. As an example, if $r = 10$ for the constant volume cycle, the Otto cycle for the same maximum pressure, *i. e.*, 25 atm., and the same amount of heat furnished, would have a ratio of compression $r_1 = 4.9$

9 In the figure, the surface *A B C D* represents all the possible efficiencies of the constant pressure cycle for the ranges of r and

d covered. In the same way the surface A_1 B_1 C_1 D_1 shows the efficiencies for all the possible constant volume cycles. The factor d does not appear in the equation for this cycle, hence the efficiencies are constant in this direction. The two surfaces intersect in the line E F, and for the conditions assumed, therefore, the constant pressure cycle is superior to the constant volume cycle for all cycles in the surface F E D C B F. In the only commercial constant pressure engine, the Diesel, the value of d at full load is about 2.5, and r is in the neighborhood of 13. It is seen from the diagram that the superiority of the constant pressure engine is

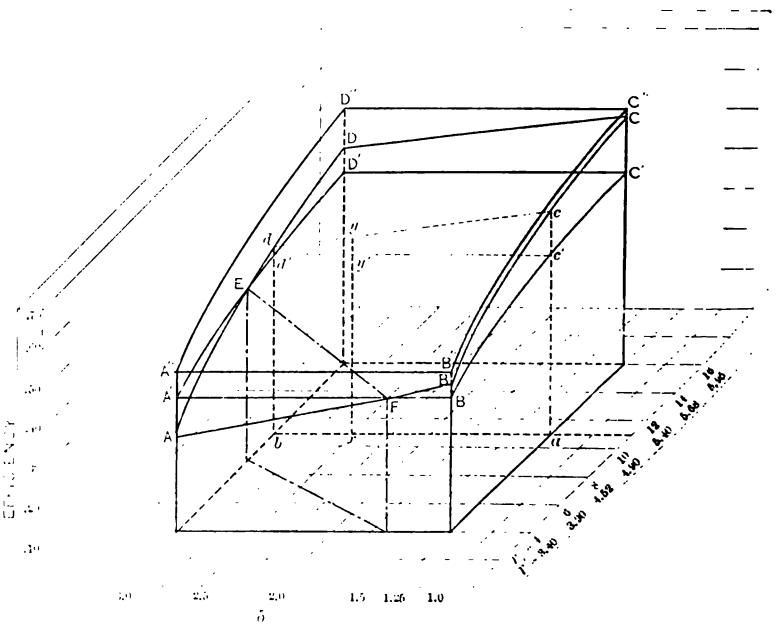

FIG. 1 DIAGRAM SHOWING EFFICIENCIES OF THE OTTO CYCLE

considerably under these conditions. In making comparisons by this diagram it should, however, not be forgotten that the cycles treated are ideal, and that in practice, while the results are similar, the gain due to the constant pressure principle is probably not so great as indicated.

10 The diagram is drawn by isometric projection, and to show how comparison may be made by means of the diagram, assume that the constant pressure engine has a compression ratio of r 11. The equivalent ratio for the constant volume cycle of the same maximum pressure (25 atm.) and the same amount of heat

received would be about $r_1 = 5.15$. Assuming full load conditions, *i. e.*, $d = 2.5$, we proceed as follows:

11 From $r = 11$, draw a line a-b parallel to the d axis. From a and b draw lines parallel to the efficiency axis cutting the curve $B\ C$ in c and the curve $A\ D$ in d; join c and d. Then from the point of intersection of $d = 2.5$ and the line a-b draw the line x-y parallel to the efficiency axis. The distance x-y as scaled off on the efficiency axis represents the efficiency of the ideal constant pressure cycle for the conditions assumed. Next, join the points d^1 and c^1 which represent the intersection of the lines a-c and b-d with the limiting curves of the constant volume surface. Then x-y represents the corresponding efficiency of the constant volume cycle. As scaled off, x-$y = 50$ per cent and x-$y^1 = 46$ per cent. Actual computations show the figures to be 49.8 per cent and 45.6 per cent, respectively.

12 The diagram further brings out the fact that, in theory, the efficiency of the constant pressure cycle increases with a decrease in d, that is, with a decrease in the load. This is borne out in practice in Diesel engines, where many tests have shown a greater thermal efficiency at $\frac{3}{4}$ than at full load. Further down in the load curve this action is overbalanced by other losses in the machine and it no longer appears.

13 Finally, the surface $A''\ B''\ C''\ D''$ represents the efficiencies of the constant volume engine when the compression pressure is the same as in the constant pressure cycle; *i. e.*, r is the same for both. As pointed out, this results in superior efficiencies for the Otto cycle throughout, but in the ordinary operation of the Otto cycle, pre-ignition would prevent the uses of values of r exceeding eight even for the lean gases.

Mr. J. E. Johnson, Jr. No one who has read this paper carefully can fail to realize that the author had an exceptional grasp of the subject and has treated it along broad lines.

2 There are some points to which I wish to call particular attention in relation to this general subject. My particular reason for desiring to be heard in this matter is that it concerns itself intimately with the engines of blast furnaces, and being one of the few blast-furnace men who are members of this Society, it is possible that I can throw a little additional light upon the subject.

3 In the first place it seems permissible to call attention to the Appendix of Mr. Junge's paper and particularly to the comparison of the theoretical efficiency of two cycles, first, the ordinary Otto cycle,

and, second, the cycle of the controlled combustion motor of which the Diesel is the most prominent type, paragraphs 85 and 88. It would seem that the theoretical efficiency of the controlled combustion type is 55.6, while that of the Otto is 51.4 per cent; on the other hand the maximum temperature of the Otto is 2348 degrees as against a maximum temperature of 1954 degrees in the controlled combustion type. As the high temperature reached by the internal combustion engine presents one of the most serious obstacles in its design, it is not easy to see why the controlled combustion type has not beaten the Otto cycle off the field altogether, and as things in engineering are, in general, most successful which conform the most closely to natural laws, these figures seem to indicate that the ultimate development of the gas engine will be more in the direction of the Diesel type with its great resemblance to the diagram and characteristics of the steam engine, than in the direction now so strenuously pursued.

4 This is more particularly true if we consider one of the possibilities of power transmission of which no mention has as yet come to my attention. This consists in the transmission of combustible gas under such initial pressure that the discharge or terminal pressure will be high enough to be used directly or with slight additional compression in the cylinders of a Diesel engine, the advantage being that all ordinary piping is strong enough to carry many times the ordinary pressures used and the necessary precautions for making tight joints at this high pressure do not increase the cost of the line in anything like the degree that the increased pressure augments the carrying power of the pipe.

5 It is a fact not generally appreciated that gaseous friction in pipes depends, under given conditions, upon the difference of the squares of the initial and terminal pressures. Thus the drop in pressure from 500 pounds down to 400 pounds would convey the same quantity of air as would be conveyed by the drop in pressure from 300 pounds down to atmospheric. The insignificant increase in power to compress to 500 pounds instead of 300 pounds is perfectly well known, and the net result is that for a slightly great expenditure for pipe line and for energy of compression, we should have gas delivered at a pressure which would enable it to be used directly in the cylinder of a Diesel engine without further compression, making a great simplification of the engine and giving an enormous capacity of transmission to a pipe line of very moderate size.

6 In considering the general subject of cheap power development and its cheap transmission from coal fields to points of consumption,

a scheme of this kind is worthy of the most careful consideration; the facts being that the efficiency of compressed gas transmission as compared with that of electricity is very much higher than is generally appreciated. As regards the general subject of the use of gas engines in place of steam engines, especially in connection with blast furnaces, many extravagant claims have been made—statements totally out of range of a reasonable possibility, and Mr. Junge, himself, has stated that the gas consumption for a given power was as 1 to 3 in favor of the gas engine as compared with the steam engine. It is statements of this kind and of the more exaggerated kind, just mentioned, to which I desire to take exception.

7 Mr. W. H. Booth, of London, generally so edifying and informing in all that he writes, recently made the prediction that the blast furnace would eventually come to be used as a gas producer first and as an iron producer secondary, the iron being a by-product; while "Power," one of the best edited of all the technical journals, recently had a pair of comparative pictures on its front cover, one showing an open top furnace of a kind which has not been common for more than 40 years and in the other the gas-electric plant and its magnificent transmission system. The impression left in the mind of the casual beholder would undoubtedly be that until the advent of the gas engine, the conditions presented by the other picture had prevailed.

8 Mr. Junge also in paragraph 22 says: "These gases were formerly wasted either by inefficient methods of transformation or by blowing them into the air. They were, therefore, called 'waste gases' and were marked in the columns of plant economics as having no commercial value whatsoever." As far as blast furnaces are concerned, the top of the furnace has been closed with the purpose of leading off these gases to points of utilization, for 30 years in the writer's personal recollection and for 15 or 20 years before that time. In a broad sense, therefore, both the picture in "Power" and the statement of Mr. Junge are utterly incorrect.

9 As regards the method of transformation it has, in many cases, been very wasteful; the poorest type of boilers, the most uneconomical type of engine being employed at blast furnaces, but as blast pressures have arisen demanding more work from the blowing engine, the economy of the machinery has been increased in much greater ratio, so that for 10 or 15 years past there has been a strongly marked tendency at every works which desired to keep up with the procession, to install an economic type of boiler (generally water-tube) and cross compound condensing blowing engines, with Corliss valve gear, a

combination which it is safe to say will yield a horse power with ½ the quantity of gas employed under the old regime.

10 This tendency is so universally prevalent that the standard of comparison with the gas engine, must no longer be the old type of uneconomical boilers and engines, but the best modern type of steam machinery, whose economy would probably be not worse than 16 pounds of water per horse power per hour. That the gas engine has a decided advantage in fuel economy over an engine even of this type is not to be denied, but it seems probable that the advantage is not in the ratio of 3 to 1, as claimed by Mr. Junge, but much more nearly 3 to 2, in other words, instead of saving ⅔ of the gas used by such apparatus, the gas engine cannot save under commercial conditions probably much more than ⅓. To account for the apparent disregard of even this considerable saving, it is necessary to realize the conditions of blast furnace operations, a thing which power experts have seldom been able to do.

11 This subject is so large that it is impossible to give an adequate idea of it in a brief discussion of this kind, and it would, moreover, be out of place here. It is, however, safe to say that there is no apparatus in metallurgy in which the capital invested and the value of the output are both so high as in the blast furnace. There is, therefore, a very heavy fixed charge of labor, interest, depreciation, and other factors, amounting to from $1.50 to $2.50 per ton of iron produced, which goes on just the same whether the furnace is in operation or not. In many cases, furthermore, the steel works are an adjunct to the blast furnace immediately dependent upon it for their operation and having a still larger interest charge against their output. A suspension of operations, therefore, at a blast furnace means not only loss of profit on iron not made, but also the loss of this fixed charge. The result is that the machinery and the furnace must be reliable in the first, second, and third places and economical in the fourth.

12 Any attempt to regard the blast furnace as an adjunct to the power plant may be technically correct but is commercially foredoomed to failure, as the following illustration will show. A certain large steel work in this country has adopted the gas engines for blowing purposes and also for electrical generation: three of the furnaces were connected to the gas main supplying this machinery, two of these, for some reason, which is immaterial to this discussion, went out of commission temporarily, and the third one was supplying gas for the gas engines. It had steam blowing engines, available for its own use, but the furnace superintendent had never caused a shut down to the electric station and he was very anxious not to do so.

This third furnace began to show symptoms of those sudden ailments to which blast furnaces are liable, and for the remedy of which a stop was necessary, but the superintendent was determined that he would not shut down the gas engine plant and would not stop this furnace until he could get one of the others into operation. By doing so, he saved the gas engine plant from a shut down, but when the relief furnace was put on the other was in such a state as to demand 10 days of terrific work and expense, with practically no output during that time. As this furnace was probably making in the neighborhood of four hundred tons per day, worth something like $15 per ton at the furnace, the loss of output during this 10 days amounted to $60,000 or thereabouts, while the loss in fixed charges and profits was possibly not less than $20,000. This may be taken as a typical case of a possible occurrence at a plant with gas-driven blowing engines; of course, not a very frequent occurrence but sufficiently expensive in every sense to compensate for its rarity. The benefits, on the other hand, which are to be obtained by gas driven blowing engines through the utilization of surplus power are to be obtained in only a slightly reduced degree by the use of good steam machinery.

13 At the plant of which the writer has charge, we are now constantly on the edge of being short of steam, but we have under construction a cross compound condensing engine of Nordberg build, and have under reconstruction our boiler plant, so that we shall be able to use 125 pounds of steam pressure and will have, when we are done, a first-class plant of water tube and horizontal tubular boilers. We are so sure that we shall then have a large excess of steam that we now have on the ground, ready for erection, a large air compressor and power engine combined, for transmitting air a mile to the mines, developing power for various purposes, driving the washer, running the pumping plant at the river, running all the shops at the plant, etc.

14 From previous experience with a similar type of blowing engine and much poorer boilers at another plant we are perfectly certain that we shall have ample steam for these purposes, and expect to have available four or five hundred horse power more at the least calculation, all from a 100 ton stack running with a moderate coke consumption. We have under contemplation the erection of an auxiliary plant which will utilize some of this surplus power in addition to the uses already mentioned.

15 Does not this seem very much like the story of the advantages to be obtained by the use of the gas engines? Is not the difference much more one of degree than of kind? Does the gas engine mark the epoch in contrast with good steam machinery or only in compar-

ison with poor? These are questions which will be answered according to the balance between the commercial and the scientific perceptions of each individual. There is no question that for large plants of three furnaces or more, which can safely count on a supply of gas from at least one of these at all times, the gas engine will eventually come to be used for blowing engines and other power purposes, especially if the location of the plant is such as to provide a market for the surplus power thus made available, but at the isolated plant where the engines drive the furnace and the furnace drives the engine, as long as all goes well, they are valuable—but not when things go badly. It would be an intrepid manager who would stake all on the use of a gas blowing engine. Not merely because the gas blowing engine is less dependable than the steam engine (though it undoubtedly still is), but because the supply of gas is liable to fail suddenly just at the time when it is needed most, a condition which can be met in the steam driven plant by simply burning coal under the boilers already in use, but in the gas driven plant it would require the starting of an idle gas producer, with the loss of several precious hours.

16 I may explain that this condition arises from the fact that furnaces sometimes "stick," that is to say, the stock in the anterior of the furnace becomes packed and impermeable to the blast, the pressure rises enormously, and at the same time but little blast forces itself through, cutting off almost entirely the supply of gas from the furnace to the power plant. It is absolutely essential at such times that the engines continue to run against that heavy pressure without a moment's intermission, under penalty of losses in labor, money, and anxiety, which are frightful to contemplate. It is no exaggeration to say that a three hour loss of time under such circumstances might result in a loss equal to one-half the value of the blowing plant. The furnaceman is compelled on this account to regard machinery, not as an end itself, but as a means to an end, and I have frequently thought that while all well-regulated schools of mechanical engineering should have a course on the scientific use of machinery, all metallurgical schools should have a course on its deliberate, scientific, and commercial abuse. The refinements which constitute the glory of mechanical engineering being utterly insignificant in the presence of the necessities of metallurgy, if considered from the commercial point of view.

17 The time of the gas engine is undoubtedly coming; but let it not be too readily assumed that the metallurgical industries deserve to have the finger of scorn pointed at them because they have not instantly adopted so great a scientific improvement.

18 These remarks are intended as a defense of the attitude of the metallurgist and as a warning against hasty and ill-considered judgment on this subject.

DR. C. G. ATWATER In discussing Mr. Junge's paper, it is but fair to warmly commend the broad position that it takes, and to compliment the author on the thoroughness and extent of the technical information that it displays. This paper, together with Mr. Junge's other contributions to the literature of the gas engine, form a notable addition to the published information on the subject. The assumption of the scientific point of view, and the discussion of subjects from this side seems to be a method of study that the American engineer and the American manufacturer are by no means overprone to adopt. All the more, therefore, we should welcome a paper of this character, particularly when on so timely and vital a subject as the gas engine.

2 Any criticisms that I have to offer bear on matters of detail, and are of small value when compared to the paper as a whole.

3 In paragraph 22, Mr. Junge appositely sums up the proper methods of appraising waste gases as corresponding to a certain weight of coal, a certain weight of steam, or according to "some other standard, depending upon local conditions." As regards the waste gases from the beehive coke ovens of the Connellsville and other regions, it is hard to say what the local standard is, but it seems certain that it could not be replaced by a lower one, as they are now worth less than nothing.

4 In paragraph 32, he says that it "cannot be said that the gasification of coking coals is an accomplished fact." If this refers to the use of the suction producer, it is doubtless true, as far as my information goes, but if it is to include the pressure type of producer as well it seems somewhat too sweeping. Bituminous coking coals are not favored by any means by those who wish to operate gas engines, but it is hardly fair to say that it cannot be done. Some of the tests made at the St. Louis Station by the United States Geological survey were presumably on coking coals, notably those from Alabama and West Virginia. It is not so stated, but as far as can be judged, they seem to have been of that nature. Also in the later lines of this paragraph, mention is made of the method of fixing tarry vapors in gas from such coals by drawing through an auxiliary fuel bed. If this method is successful, it removes one great objection to the use of bituminous coals in the producer by eliminating the cleaning plant. The numerous gas producers in operation in the Pittsburg and other districts where a coking coal is the cheapest, are evidence that such a coal

can be worked, though I am not aware that the gas is used for gas engines.

5 In note to paragraph 47, it is stated that the gain which can be effected from the sensible heat of the gases in steam boilers, from their sensible and inherent heat, or from their combustion in gas engines is the same for the beehive coke oven, the by-product oven, or the regenerative oven. The point of distinction between the by-product and the regenerative oven is not clear, nor does it seem possible that as much available heat can in practice be recovered from a beehive oven, the waste gases from which are led through a steam boiler, as can be recovered from a regenerative by-product coke oven, wasting only the heat of the exit gases, and from the regenerators delivering a maximum of heat in the form of surplus gas.

6 Exact data for comparison are hard to secure, as tests of beehive ovens in connection with boilers are few, and do not show even fairly favorable results. I would like to know, therefore, the data on which this conclusion is based.

7 Further, Mr. Junge states that in ovens of the latest Otto type, up to 4940 cubic feet of gas of 448 B.t.u. is obtained as surplus; this figure has been much exceeded by ovens in this country, which have delivered 30 per cent or 40 per cent more heat units than this, the surplus approaching or equaling the above figure in quantity, and far exceeding it in calorific value.

MR. A. J. WOOD It may be noted that the efficiency for the ideal Otto cycle at full load is 51.4 per cent and for the constant pressure cycle 55.6 per cent. One might, at first, be led to infer from this that, in general, the Diesel engine cycle gives a greater efficiency than the Otto. It should be noted, however, that the compression volume was different in the two cycles; the author has taken the same maximum pressures in the cases cited. Had the Otto compressed to the same *volume* as the Diesel, the efficiency in the former cycle would have been:

$$\eta_t = 1 - \left(\frac{v_2}{v_1}\right)^{n-1} = 1 - \left(\frac{22.72}{222.72}\right)^{.41} = 59.2 \text{ per cent},$$

thus giving 3.6 per cent in favor of the Otto instead of 4.2 per cent in favor of the Diesel.

2 The efficiency of the Diesel cycle may be expressed in the following form, which will serve to show at a glance its difference from the Otto efficiency:

$$\eta_t = \frac{Q_1 - Q_2}{Q_1} = 1 - \left(\frac{v_2}{v_1}\right)^{n-1} \cdot \frac{1}{n}\left(\frac{R^n - 1}{R - 1}\right); \text{ where } R = \frac{v_3}{v_2};$$

from which it is evident that the efficiency will increase as R (or the load) decreases. For example, suppose the load drops off one-half, the influx of heat being $\frac{Q_1}{2}$, then R will decrease 50 per cent, but the efficiency will increase. This is exactly what the author finds and brings out in paragraphs 88 and 89.

3 Again, turning to the Otto; with quantity regulation, the author shows that the efficiency decreases with decrease of load; examine the equation:

$$\eta_t = 1 - \left(\frac{v_2}{v_1}\right)^{n-1}, \text{ with quantity regulation,}$$

as v_1 decreases (the compression volume v_2 remaining the same) the efficiency decreases; but with *quality* regulation, v_2 and v_1 remain the same and the efficiency of the whole cycle is unchanged—a striking contrast to what is found in the Diesel.

4 Do not these observations point favorably to the Otto theoretical cycle in preference to the Diesel on the basis of a comparison for full load and *quality* regulation? One would not hold, of course, that the Otto engine can practically compress to the amount of the Diesel and then explode the charge at constant volume. I am referring here to the theoretical cycles only.

MR. GEO. J. RATHBUN The following remarks apply only to engines governed by varying the quantity of mixture admitted to the cylinders during a cycle, and are intended to suggest, rather than prove, certain possibilities that, according to the writer's personal experience, seem to be worthy of consideration.

2 Overload capacity in a gas engine is obviously a necessity. Engines of this type are rapidly taking the place of steam engines for all classes of service, and they are consequently called upon to handle variable loads and large overloads of short duration. This is particularly true in electrical transmission, where a large variable motor load is obtained. In operating on producer gas, there is liable to be a variation in the quality of the gas. If the engine has no overload capacity the installation will not be satisfactory. As long as the highest economy is obtained at maximum load, manufacturers and users will be disposed to rate the engines as near the limit as possible. It is reasonable to suppose that builders would be glad to rate their engines to carry a 35 per cent overload, if the economy at rating was practically the same as at maximum overload.

3 Mr. Junge in paragraph 13 deplores the lack of overload capacity in gas engines, stating that the difficulty cannot be overcome, being inherent in the cycle. The writer believes this statement to be unwarranted, and will try and offer a few reasons to substantiate his conviction.

4 It is obvious from a consideration of the Otto cycle, that increased compression means increased economy. This cycle, however, is never obtained in an operating engine. We must consequently look to the engine itself if we are to consider its limitations and possibilities.

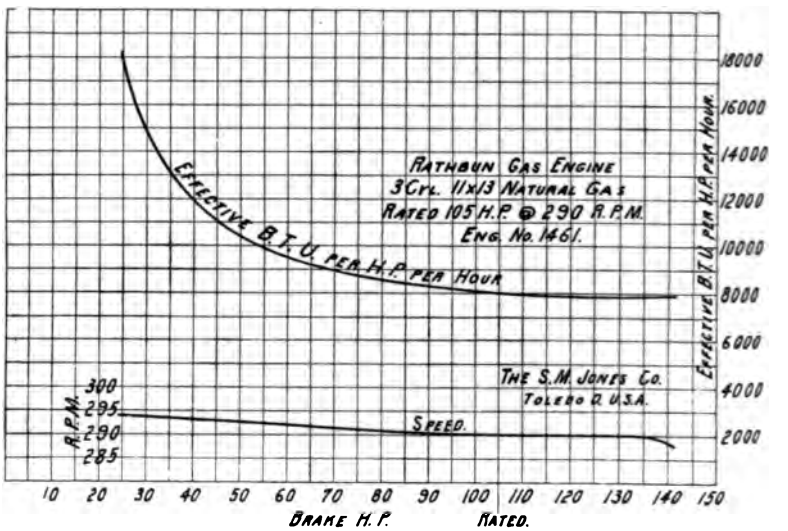

FIG. 1.

RATHBUN GAS ENGINE, 3 CYLINDER 11 x 13, NATURAL GAS. RATED 105 H.P. AT 290 R. P. M. ENGINE NO. 1461

5 Compression does not appear to be the most important factor in economy when it is remembered that there are various engines on the market today, all having the same compression pressure, but delivering a brake horse-power hour on from 8000 to 16,000 effective B.t.u., respectively.

6 Gas engine builders are familiar with the fact that each particular engine has its limit of economical compression pressure. If carried beyond a certain point there is no increase in economy or mean effective pressure. The effect of the increased initial temperature is offset by the increased rate of radiation to the water jacket.

7 The inference seems to be obvious: design an engine that will give a brake horse-power hour on 8000 B. t. u.; proportion the clearance so that the maximum indicated thermal efficiency is obtained at 26 per cent below the maximum horse-power. This will give the engine an overload capacity to 35 per cent with practically uniform efficiency.

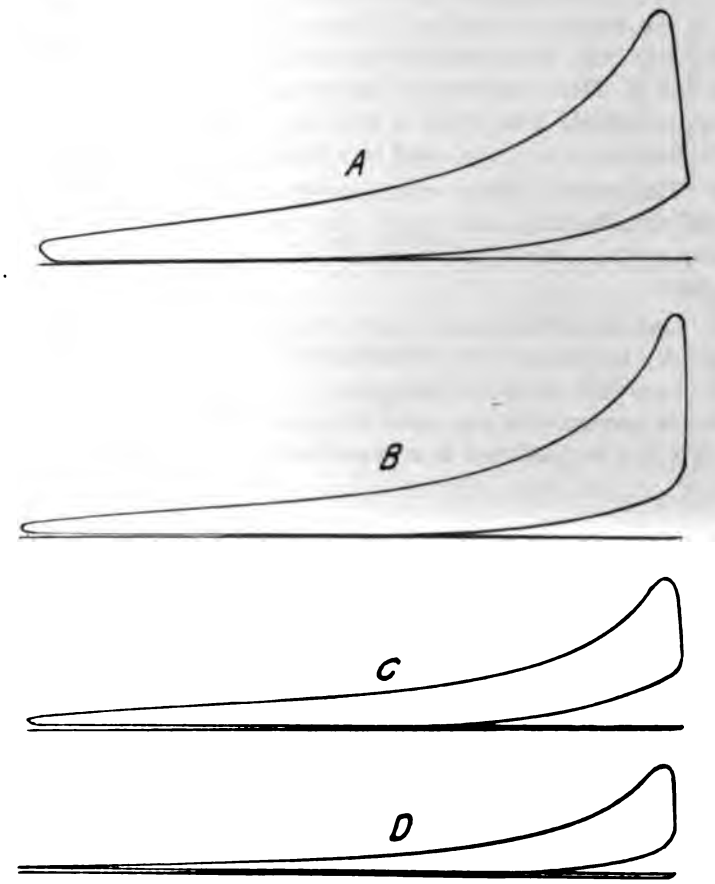

FIG. 2 CARDS TAKEN FROM ENGINE AT OVERLOAD, RATED LOAD 50 PER CENT AND 25 PER CENT

8 This proposition undoubtedly offers difficulties, particularly on some designs, and like all ideal conditions can only be approached in practice. The writer is of the opinion that investigations along this line will be barren of results, unless the engine is equipped with automatically controlled ignition. As a matter of fact, controlled

ignition will probably have more influence on developments in the efficiency of high efficiency engines than any other apparent factor.

9 Fig. 1 shows gas consumption curve on a 105 horse power vertical multiple cylinder engine, equipped with variable ignition controlled by the governor. Fig. 2 shows typical cards taken from this engine at overload, rated load 50 per cent load, and 25 per cent load. These diagrams are not offered as representing an ultimate test of the engine in question. The writer does not claim that this engine has been developed to the limit along the lines discussed. This test is offered to show relative and comparative results. It seems to indicate that there is some hope of increasing efficiencies below maximum loads, in spite of a defective cycle.

10 The writer is firmly convinced that this subject is worthy of careful consideration and regrets, for the time being, that he is a builder, not an author, and only has an insignificant amount of data to offer.

11 Gas engine efficiencies below maximum loads will eventually be greatly improved. For small units the means are probably at hand to produce the result commercially. In the case of larger units, it may be necessary to wait until structural material of higher tensile strength can be produced at a much lower cost than obtains at present.

PROF. R. H. FERNALD I desire to express my appreciation of the complete and interesting paper presented by Mr. Junge, and I can but commend the paper to the careful consideration of the Society. Inasmuch as Mr. Junge has referred to my paper of a year ago on the "Results of the Preliminary Producer Gas Tests of the United States Geological Survey Coal Testing Plant at St. Louis," I desire to take this occasion to submit in a very concise form certain summaries that may be of more or less value to those directly interested in the manufacture and operation of producer plants.

2 The figures given below could not be presented a year ago for the reason that the data upon which they are based had not then appeared in Government print.

SUMMARY OF FUELS TESTED BY THE GAS PRODUCER DIVISION, UNITED STATES GEOLOGICAL SURVEY FUEL TESTING PLANT, ST. LOUIS, MO., DURING THE YEAR 1905

	Number from each State	
BITUMINOUS COALS TESTED		
Brazil	1	
Illinois	16	
Indiana	7	
Kansas	1	
Kentucky	4	
Ohio	7	
Pennsylvania	7	
Virginia	4	
West Virginia	5	
Wyoming	2	
	—	54
LIGNITES TESTED		
California	1	
North Dakota	3	
	—	4
MISCELLANEOUS		
California lignite and cinders	1	
Coke breeze	1	
	—	2
DUPLICATE TESTS		
California lignite and cinders	1	
Illinois coal	1	
Indiana coal	1	
Pennsylvania coal	1	
	—	4
Total tests made		64
Average B.t.u. per pound of coal as fired	12,500.	
Average B.t.u. per pound of lignite as fired	7,526.	
Average B.t.u. per pound of dry coal	13,420.	
Average B.t.u. per pound of dry lignite	10,870.	
Average B.t.u. per cubic foot of gas from coal	151.	
Average B.t.u. per cubic foot of gas from lignite	161.	
Average cubic feet of gas per pound of coal as fired	59.8	
Average cubic feet of gas per pound of lignite as fired	29.1	
Average cubic feet of gas per pound of dry coal	64.4	
Average cubic feet of gas per pound of dry lignite	40.9	
Average pounds of coal as fired per square foot of fuel bed area	8.0	
Average pounds of lignite as fired per square foot of fuel bed area	14.5	

Average pounds of dry coal per square foot of fuel bed area	7.4
Average pounds of dry lignite per square foot of fuel bed area	10.1
Average[1] equivalent pounds coal as fired per e.h.p. developed	1.74
Average equivalent pounds lignite as fired per e.h.p. developed	2.94
Average[1] equivalent pounds dry coal per e.h.p. developed	1.56
Average equivalent pounds dry lignite per e.h.p. developed	2.04
Ratio of total coal per e.h.p. (under boiler) to total coal per e.h.p. (in producer) equals	2.7
Ratio of total lignite per e.h.p. (under boiler) to total lignite per e.h.p. (in producer) equals	2.6
Pounds of mixture of tar, water, soot, etc., delivered by tar extractor per ton of coal	385.
Pounds of mixture of tar, water, soot, etc., delivered by tar extractor per ton of lignite	175.
Average sulphur in coals tested	2.55 per cent
Average sulphur in lignites tested	2.00 per cent

AVERAGE OF GAS ANALYSES	From Coal	From Lignite
Carbon dioxid (CO_2)	9.5	9.1
Oxygen (O_2)	0.0	0.0
[2]Ethylene (C_2H_4)	0.0	0.0
Carbon monoxid (CO)	19.2	22.6
Hydrogen (H_2)	12.4	14.6
Methane (CH_4)	3.1	3.0
Nitrogen (N_2)	55.8	50.7
	100.0	100.0

[1]This includes all coal charged to producer and coal for auxiliary boiler.
[2]Not separated from methane (CH_4) in this series of tests.

3 In presenting the accompanying charts too much emphasis cannot be given to the fact that the tests from which these curves were deduced have been subjected to absolutely no refinements. With the possible exception of two or three coals, one test only has been made on each fuel, and the result of each test has, to a great extent, depended upon the ability of the producer operator to "catch on" to the methods of handling a given coal within the eight or ten hours allowed preliminary to the official test.

4 To illustrate, tests Nos. 71 to 74 inclusive, taken in consecutive order, were upon coals from Pennsylvania, North Dakota, Ohio, and Virginia.

It should also be borne in mind that all the tests have been made on one type and in one size of producer—a type designed primarily for

anthracite coal—and that it has been imperative that the test be made and the required power generated without regard to the proper relations between the gas producing qualities of the coal and the fuel bed area.

5 The restrictions have been such that the tests have been conducted on the basis of steady load on the engine (235 brake horse power) and not on the basis of maximum power producing quality of the coal.

6 In spite of those restricted conditions, the general conclusions derived from tests upon fifty odd coals made during 1905 are regarded as sufficiently significant for presentation at this time, although subject to modification in the light of later investigations. They are accordingly indicated in the following diagrams:

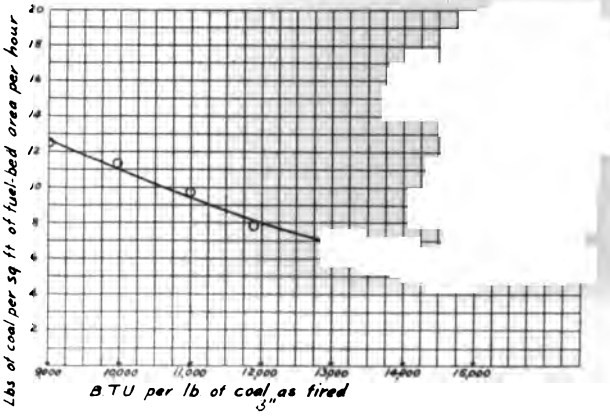

FIG. 1

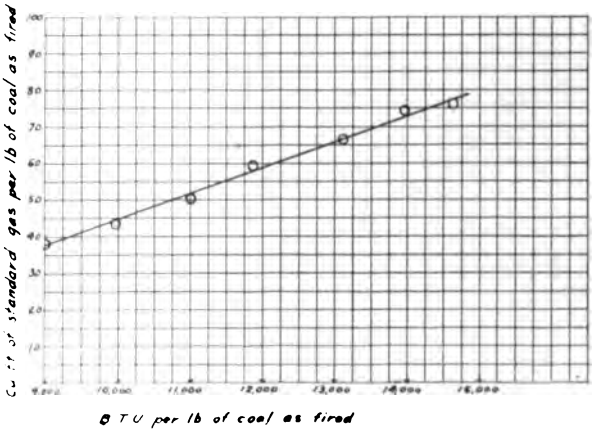

FIG. 2

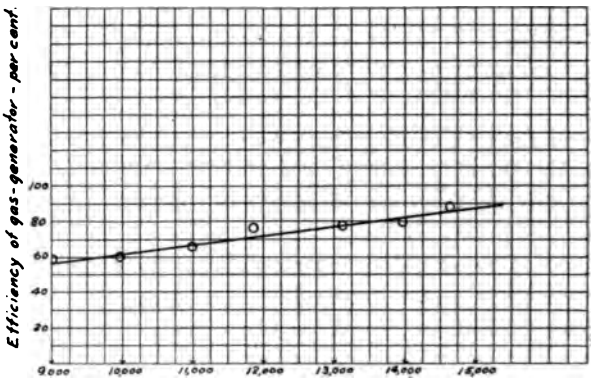

FIG. 3

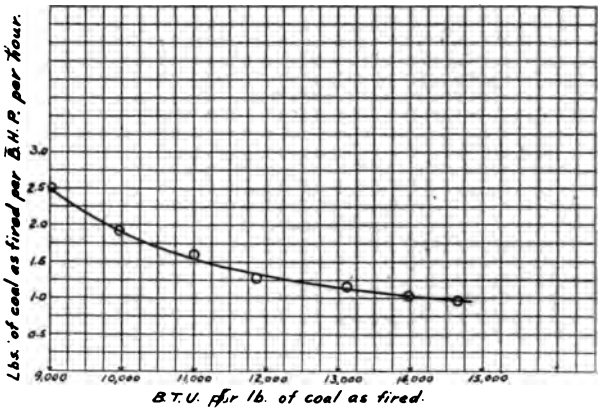

FIG. 4

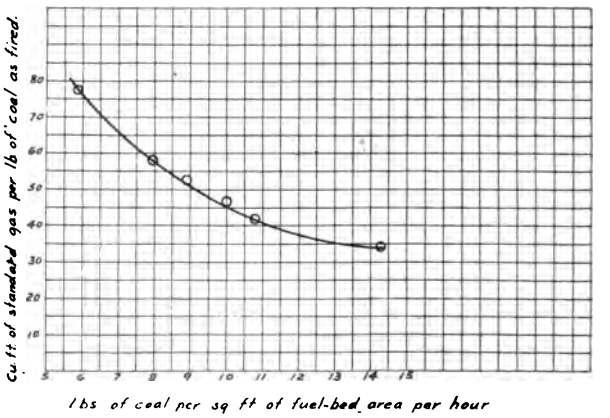

FIG. 5

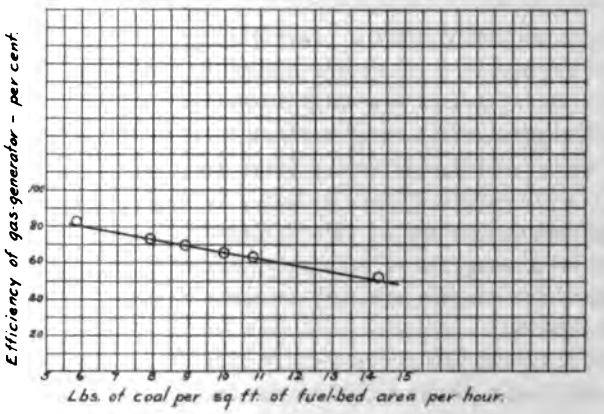

FIG. 6

MR. R. E. MATHOT After the very elaborate papers that have been read regarding the question of growing interest of the application of gas engines and producers, I think it will not be useless to lay before you some figures that will illustrate the present status of this matter on the European continent, from where, I believe, I am the only member attending this meeting.

2 In addition to the very interesting papers presented by Mr. Junge and Mr. Bibbins, and discussed by such authorities as Professor Lucke and Professor Fernald, I should like to present in a few words the leading principles that are now ruling the European construction of large engines and the results that have been derived from the application of these principles.

3 The iron and steel industry is the one which has mainly caused the rapid growth of large gas engines, and Germany has kept at the head of the development, owing to the importance of its metallurgical industries. In that country, it has been recently stated that among 50 smelting works actually at work, 42 are already using, or have ordered, large engines for dealing with the gas generated in the blast furnaces, or smelting ovens, or coke ovens. This represents 350 units that give an aggregate output of about 400,000 horse power, the largest of these plants being 35,000 horse power, while there are fifteen works using plants of 10,000 to 12,000 horse power. In some of them provision is made to work with producers only in case of need, to keep the plants at work.

4 In collieries and coke oven works, the competition by internal combustion engines against steam engines is difficult on account of

the great number of old ovens from which the available heat can only be used in firing steam boilers. In these installations, however, the number of engines at work or in contemplation amounts to twenty or twenty-five, aggregating a total output of 35,000 to 40,000 horse power. Almost all of the engines used in both smelting works and collieries are of the double acting form, some of the two-cycle and some of the four-cycle type, the latter being, of course, the more largely applied on account of their higher efficiency.

5 The increasing favor which large gas engines have met in metallurgical works will be easily realized if you bear in mind the following figures:

An ordinary blast furnace of a daily output (24 hours) of 100 tons of pig-iron liberates about 315,000 cubic feet of gas which is available for motive power and is of an average heat value of 110 B. t. u. This volume of gas generates, with steam plants, about 2500 horse power while it gives with gas engines 4200 horse power, or a difference of 1700 horse power; this is about 70 per cent more power in favor of the gas engine.

6 Such figures, of course, may not be expected unless the plants are provided with modern improved features among which the most important is means for cleaning the gas, which has, in recent times, been the object of the greatest attention on the part of manufacturers of large gas engines as well as on the part of the users themselves.

7 To get rid of the general impurities that the gas contains, such as dust, tar, and chemicals, which would be detrimental to the good working of the engines, as well as in view of reducing the temperature of the gas before delivery to the cylinders, thorough cleaning, scrubbing, and cooling are necessary.

8 These operations are effected by means of fans, rotary washers, or the like, that involve a water consumption ranging from 0.25 to 0.40 gallon per 100,000 cubic feet of gas. The content of dust can by this process be reduced from 0.3 to 0.2 of a grain.

9 The power required for operating the fans and the washers, depending on the system used as well as the amount of impurities to deal with, ranges from 1.5 to 4 horse power per 100,000 cubic feet of gas, that is, about 3 per cent of the power generated from the gas. With respect to the engines themselves, the cooling water required per hour per brake horse power for pistons and piston pins is from two to three gallons, and for cylinder jacket, etc., from seven to ten gallons. Lubrication in a good engine can be effected with one to 1½ grams of oil per brake horse power hour.

10 In Europe, if within the short period of ten years we have

succeeded in installing about 750,000 horse power of internal combustion engines, this is chiefly due to the application of successful methods and principles derived as much from theoretical knowledge as from practical hints afforded by a wide field of experience. Our makers have also been more stimulated by keen competition and the necessity of dealing with more expensive fuels than those of America.

11 In view of meeting as closely as possible one of the unquestionable advantages of the steam engine, with which we have to compete, we aim to build our gas engines with such dimensions that they afford a large margin of power and despite the possibility of reaching in our best constructions the very high mean effective pressures of 90 and 95 pounds per square inch, we rate what may be called the constant working power on a pressure of about seventy-five pounds.

12 With respect to the economy with which the American makers will before long have to compete, it may be stated that nowadays our good four cycle makers reach the thermal efficiency of 30 per cent as an average, relating to the effective horse power. This corresponds to about one brake horse power hour with 8500 B.t.u., which is realized in small single acting engines, as well as in large double acting engines, when working at normal load.

13 About this, let me observe that I have heard of certain American inventors who claim to reach much higher efficiencies with their plants. Tests made recently on small producers purport to show for the complete plants, including generator and engine, 36 to 40 per cent thermal efficiency, after a trial of—two hours! Others state that their producer has 100 per cent efficiency, and still others would convert nitrogen into available power! I know that from both the industrial and commercial points of view, American conditions are rather different from those in Europe, but I can hardly believe that the differences extend to the nature of your nitrogen, while ours on the old continent has remained obstinately inconvertible. Surely the question of gas power is interesting enough of itself, without having to advocate it in sweeping assertions that are liable to be more detrimental to the good fame of this motive power than modest and unquestionable truth.

14 Now, allow me to select some results of tests made by some of our leading authorities, and some taken from 200 trials that I have been called to make myself, either as an independent consulting engineer or as a referee to the courts.

a Trial of ten hours with prony brake on a 40 brake horse power suction producer and single acting engine of the Maschinenfabrik Winterthur =

Consumption per brake horse power at full load, 0.7 pounds

Consumption per brake horse power at half load, 0.94 pounds of anthracite coal of 13,850 B.t.u., including ashes and moisture.

b On a similar engine I had already found with illuminating gas a consumption per brake horse power hour at 4/5 load of 17.6 cubic feet of gas, referred to 0° C. and atmospheric pressure, of a heat value of 545 B.t.u. (lower value).

c Test made by Professor Schröter on a Güldner engine and producer; piston bore 250.6 mm. × stroke 400.3 mm.

TEST WITH ILLUMINATING GAS

Load Ratio	R.p.m.	M.e.p. kg. per. sq. cm.	Load i. h. p.	Heat value cal. per cu. meter	Consumption per hour per i. h. p. ref. to 0° C.; 760 mm. bar		Thermal ind. efficiency per cent
½	213.9	4.48	21.	4420	0.3975	0.376	33.9
¾	212.8	6.71	31.3	4410	0.347	0.328	38.8
full	214.5	8.06	37.7	4430	0.3435	0.327	39.
full	210.7	7.76	35.9	4440	0.3145	0.298	42.7

WITH SUCTION FUEL GAS FROM ANTHRACITE FUEL

Load	Rev.	M.e.p. kg.	M.e.p. lbs.	I.h.p.	Heat value cal. per kg.	Heat value B. t. u. per cu. ft.	Gross con. per B.h.p. hour. kg.	Gross con. per B.h.p. hour. lbs.	Thermal eff. ind.
Full	210	7.6	108	34.9	7780	13.878	0.336	0.739	28.5

TESTS WITH DIFFERENT FUELS ON NURNBERG SINGLE-ACTING ENGINES

	No. 1	No. 2	No. 3
Plant			
Fuel	anthracite	coke	illum. gas
Working load; h. p.	107.4	110	152.8
Consumption per indicated h. p. hr. in engine.	0.78 lbs.	0.93 lbs.	15.7 c.ft.
Heat consumed per i. h. p. hour in the producer suction, B. t. u.	10,850	10,840	—
	80%	75%	—
Thermal efficiency of producer, heat consumption in the engine per B.h.p. hr. B.t u.	6750	6300	6200
	80%	80%	78%
Mechanical efficiency of engine. Thermal efficiency of the plant, relating to the i. h. p.	36.3%	38.3%	36.6%

Owner's location of the plants:

No. 1 Royal Foundry of Würthemburg (Wasserflingen)

No. 2 Imperial Post Office at Hamburg

No. 3 Municipal Electric Station of Greifoland

15 It should be taken into consideration that the above figures show low mechanical efficiencies because they relate to engines provided with very heavy fly-wheels for extreme regularity of rotation.

16 Regarding the consumption of large double acting engines, accurate figures are unfortunately rather seldom obtainable, those engines dealing with such large quantities of gas, that gas holders of sufficient capacity are rarely available for a reliable test. I may mention, however, a trial witnessed contradictorily by the engineers of both makers and users on a double acting four cycle engine of 600 horse power supplied by Ehrhardt & Sehmer, one year ago, to the Königlische Berginspection at Heinitz Saarbruck, Germany. After four months of constant work and without previous cleaning, this engine was tested with coke oven gas ranging from 350 to 370 B.t.u., and showed an economy of 8100 B.t.u., per brake horse power hour. The mechanical efficiency recorded, with the power under consideration, was 83 per cent. The engine was a new one and was tested under normal load at 150 revolutions per minute. The principle dimensions are: cylinder bore, 620 mm.; piston stroke, 750 mm.; diameter of rods, 170 mm. The load reached 520 kilowatts with a three-phase dynamo mounted on the crank-shaft of the engine. It will be seen that even for the normal load, the above figures show a thermal efficiency of about 31 per cent on the basis of brake horse power and 37.5 for the indicated horse power.

17 High efficiencies, smooth running and reliable working are all obtained, thanks to the following principles that are now applied by almost all European makers and govern their construction. The compression has been raised to 160 and even to 190 pounds in order to obtain reliable ignition of the very weak and lean mixtures used for purposes of economy.

18 High compression involves high temperature and we have therefore to design the combustion chamber to allow even cooling and free expansion of the cylinder head. We aim also to design the combustion chamber of such a shape that it affords the maximum volume with the minimum cooling surface and facilitates high velocity of flame propagation in the explosive mixture as well as thorough combustion without the sharp explosions which are of such detrimental effect in the old type of hit-and-miss engine now completely abandoned by our representative makers. In fact, whatever the quality or richness of the gas used, in spite of high compression, we aim not to reach initial explosive pressures above 330 to 360 pounds. This causes our engines to run smoothly, without the knocking or pounding due to early sharp explosions.

19 Governing is always effected by varying the mixture admitted at each cycle, whether by varying the quantity at constant ratio, or by varying the ratio of gas in a constant quantity of mixture or even by combining both processes. The first method causes, of course, variable compression and, as a consequence, some loss of power due to partial vacuum in the cylinder at low loads, but in spite of this defect its principal advantage is to give the highest efficiency at every load because it insures always a good combustion of the mixture exploding in due time.

22 The second method, although being apparently less economical, holds certain mechanical advantages that I shall remind you of later on.

23 The third method, involving a combination of both systems of variable quantity and variable quality, is claimed by its few advocates to embody the leading advantages of the two former methods, without having their weak points. But the combined system leads to the use of somewhat complicated mechanical arrangements and its successful operation might therefore be questionable. As a matter of fact the most rational course seems to consist in the selection of that one of the first two methods which suits better the character of the work the engine has to deal with.

25 In the case of high-speed engines supposed to run at a nearly constant number of revolutions, as for driving electric alternators, spinning mills and the like, the inertia of the moving parts, such as the piston, the connecting rod, etc., becomes one important factor of smooth working. The moving masses should therefore be kept at a constant speed and the system of governing by variable mixture should consequently be preferred because it gives constant compression due to the admission of a constant volume.

26 In the case of slow-speed engines, such as are used for driving blowing plants, pumps, rolling mills, etc., which allow variations in the number of revolutions to the extent sometimes of 50 per cent, the system of governing by variable quantity with constant quality of mixture will answer the purpose, despite the variation of the compression.

27 All large continental engines are made of the double-acting horizontal type, and although of different detail arrangement, the Oechelhäuser and the Dingler types give a power impulse for each half revolution of the corresponding crank. The general scheme of the automatic cut-off steam engine with valves located at both ends of the cylinder has been adopted in our gas engines as a principle. The inlet valves at the top and exhaust valves at the bottom meet both constructional and working requirements in every respect.

With regard to this, the engines of the Allis-Chalmers and the Westinghouse Companies in this country are quite up to date. The question whether their side crank is better than our center crank will be solved by future experience, though, nowadays, it answers better the American conditions regarding simplicity and facility of erection.

28 I rather agree that our European engines are too complicated and I am quite confident that when Americans have let us pay for the experience they will before long design large engines that will be much more simple and reliable, thanks to their remarkable faculty of adaptation and their well-known ingenuity. Regarding simplicity, I trust that mechanics will make a considerable step forward when the modern large gas engine has been somewhat Americanized.

MR. FRANK FIRMSTONE Neither Mr. Junge nor Mr. J. E. Johnson gives the figures on which he bases his estimates of the relative consumption of "waste" gases per horse power in gas engines and by burning them under boilers to raise steam.

2 The most complete statement on the question seems to be in Mr. Adolph Greiner's paper in "Journal of the Iron and Steel Inst.," No. 1, 1898, and No. 1, 1900. He there states (No. 1, 1898, p. 25) as the result of experiments at Seraing, that steam machinery at the blast furnaces used 26.49 pounds of water per indicated horse power per hour equivalent to 22 cubic meters of gas. The first gas blowing engine (No. 1, 1900, p. 111) used on a careful trial 2.56 cubic meters of gas per indicated horse power per hour, or less than one-eighth of the average consumption of the steam machinery of various kinds as stated above.

3 On this basis, assuming steam engines using 16 pounds of water, which Mr. Johnson indicates as possible, the gas consumption for steam engine and boiler is: $26.49 : 16 :: 22 : 13.2$ cubic meters of gas, or about five times the consumption actually realized by the Seraing blowing engine. A saving of two-thirds of the gas therefore seems a moderate assumption in this case, even admitting that the boilers might have been improved, on which point there is some information in Greiner's paper of 1898 (footnote, p. 25).

4 The writer saw the Seraing engines at work at Seraing, Dieffer-dingen, and at Messers. Cochran's Ormesby Works at Middlesborough in September and October, 1902, and also the gas engines of various makes at the Dusseldorf exhibition, then open, and engines at work at several iron works in that vicinity. As a result, previous favorable opinions were fully confirmed and today, if he were designing a blast

furnace works to include several furnaces, he would, without hesitation, adopt gas engines rather than steam engines and boilers.

5 In the case of an isolated furnace, the considerations advanced by Mr. Johnson in favor of steam might perhaps turn the scale against the gas engine. The decision would hang on the question, "How long would it take to get gas from a gas producer in good order, and charged, ready to light, compared with the time needed to get good fires under three or four boilers already under steam with gas?" As to the first part of the question the writer has no experience. As to the second, assuming that coal was at hand, and the grates in good order, as would be the case under efficient management, to get men together, to clear the bar of sand or ashes with which they must be covered to protect them when the boilers are using gas only, and, finally, for time to make the fires and let them come up an hour or an hour and a half is less time than would actually be expended in most cases.

THE AUTHOR In view of the great number of discussions advanced I will have to limit my reply to a short survey of those remarks which appear to contain some contradiction of my statements. For more detailed information on these questions I must refer those interested to my various publications in the technical press.

2 Dr. C. E. Lucke and R. E. Mathot. Dr. Lucke's discussion is noteworthy and most vital to the question. I entirely agree with him that the limitations of the gas engine, and especially its relations to the steam engine, have not been sufficiently emphasized in my paper. Unfortunately, that portion of the paper which was devoted to the questions upon which he enlarges was cut out by the editing staff of the Society, probably because otherwise the paper would have been abnormally long.

3 I can also quite understand that the situation as I presented it, basing my remarks on my familiarity with European conditions, and the remarkable performances which I recorded, must seem optimistic and even impossibly high to one who has limited his energies to the study and development of gas engines in America.

4 In this connection I find that the figures which Mr. Mathot submits in his discussion are apt to convince those who may doubt the correctness of my statements that the efficiencies recorded have actually been attained on the European continent.

5 I believe that when commenting on the evolution of gas power it is logical, necessary, and proper to give, beside the average performances of gas prime movers, which were graphically represented by several curves, also the best figures which have so far been attained

both with large and small engines, so long as they are clearly designated as maxima.

6 Mr. J. E. Johnson, Jr.: "The refinements which constitute the glory of mechanical engineering being utterly insignificant in the presence of the necessities of metallurgy, if considered from the commercial point of view." This is perhaps the most remarkable statement in Mr. Johnson's discussion. If it is meant to represent the general attitude of American iron masters, I feel at a loss to reply. It certainly stands in contradiction to the general modern tendency which prevails in European metallurgical circles. The fact that all iron smelting plants in Germany have equipped their furnaces with gas, instead of steam blowing engines will serve to substantiate my statement. However it is useless to enlarge on this question since time will give the final answer.

7 Also, I leave it to everyone to decide for himself as to whether the name "waste gases" was imparted to the gases emanating from the blast furnace when or because they were utilized, or because they were wasted. As to the technical argument, the question is this: What reserves are available for a blast furnace which has shown signs of weakness and must be closed down, thereby depriving the power section of the plant of a certain contribution or quantity of gas, which is indispensable for fulfilling all internal and external obligations that have been undertaken by the works management. It would be wrong to conclude that, owing to the remote possibility of having to close down one or the other furnace, the surplus gas emanating from them should not be utilized at all, except for covering the requirements at the furnace proper. On the contrary, in Europe engineers are endeavoring to reduce the unavoidable losses and the demand at the furnace, namely, leakage at furnace top, gas used for blowing and for heating the blast, to the lowest possible amount, in order to reserve the rest for more profitable usage.

8 Considering the case that in a plant of four furnaces one is beginning to show signs of distress and must be shut down, then one-fourth of the total quantity of gas required is no longer generated. Of this amount only one-half must be replaced by suitable means, since almost 50 per cent of the total is used for operations at the blast furnace proper, and can be dispensed with when the furnace is not working. As for the rest, it is, of course, unnecessary to replace the total quantity of gas so long as we have sources of generation available which can deliver the same amount of kinetic gas energy to the power plant. This reserve energy can be derived either from gas producers or from coke ovens, which in combined plants are always

available. Even with steam driven blowing engines, such as are employed now almost exclusively in American practice, it has been commended to provide for some means beside blast furnace gas for supplying additional power or blast at need.

9 The best equipment which can be provided for such cases of emergency consists of a bank of gas producers which can deliver a regulable quantity of rich gas to the boiler plant where it can be burnt together with the blast furnace gas under perfect control, instead of using additional boiler coal. Where these wise precautions are taken, the breaking down of one furnace would initiate no appreciable amount of trouble and no interruption in the power service, since the rich producer gas can be made to fully replace the loss of poor blast furnace gas. It is known that producers, when properly constructed and subdivided, can be overloaded by 100 per cent and more, if the necessity should arise, also that they can be put in operation from cold within a very few minutes, and that they can be fired with inferior grades of coal, mine culm, etc., of which there are enormous quantities available in every large plant.

10 Since of the three available sources of gas generation; the blast furnace, the coke oven, and the producer, none is worked at its utmost capacity under normal conditions, it is quite easy to provide for the required gas energy from the combined equipment, and without having any special reserves. Where blast furnaces are the only source of power, there the provision of spare producers is commendable both for securing greater regularity of product and for having sufficient reserve for use in the central station.

11 The electric canalization of industrial districts and the system of power exchange which is now so widely adopted in large scale operation in Europe, will tend to further secure stability of production independent of local breakdowns.

12 Mr. C. C. Atwater. It should be borne in mind that my subject is substantiated by such data only as were obtained in European practice. This explains the difference in the quantity of gas output between American and European coals. Dr. Hoffmann-Bochum is the authority quoted regarding the figures of performance of Otto ovens.

13 I will modify my statement that the gasification of bituminous caking coal is not an accomplished fact, to the effect that it is not a commercial proposition. I know of several producers in this country which were originally working with such material, but are now operating on anthracite instead, because the operative difficulties in actual practice proved to be insurmountable. For further informa-

tion reference may be had to an article on "The Application of Gas Power in Collieries" which I am publishing in the "Engineering and Mining Journal."

No. 1134

OUR PRESENT WEIGHTS AND MEASURES AND THE METRIC SYSTEM

An Argument for a Technical Commission

By HENRY R. TOWNE, NEW YORK, N. Y.
Member of the Society

Note: While this argument is addressed primarily to engineers, because their training and work imply familiarity with most of the technical facts on which chiefly it is based, and because of their intimate professional relation to organized industry in nearly all of its branches, it is intended to appeal also and equally to all other professions and interests. The questions at issue are national, not local; they affect all classes, not simply a few interests; above all they concern the plain people in their industries, commerce, agriculture and everyday affairs, not merely those whose work lies chiefly in the domain of science; they are intensely practical, not theoretical. The issues thus involved should be understood by all the people, and any laws affecting our weights and measures should be based, as all legislative enactments of universal application should be, on the intelligent and unequivocal demand of an unquestioned majority of the electorate.

1 Since 1816, when President Madison in a message to Congress stated that "no adequate provision has yet been made for the uniformity of weights and measures contemplated by the Constitution," the question thus implied has been frequently in a state of unstable equilibrium. On the one hand, usage and legislation by the States have established and confirmed our present system of weights and measures, but, on the other hand, the advocates of the metric system have persistently sought to secure its compulsory adoption. Congress in 1866 legalized the use of the latter and it has since been taught in our schools, and the development of modern science, especially in the field of electricity, has necessitated the creation of many new measures, which usually have been based on metric units. Is it not time, therefore, that the vitally important questions thus involved should be studied by a competent technical tribunal, whereby a decision may be reached, which, being based on due consideration

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of all the conflicting issues involved, shall be acceptable to all our people, and therefore, permanent?

2 Heretofore, except for informal discussions by unofficial bodies, the consideration of this subject has been limited to hearings by the Committees on Coinage, Weights and Measures of the two Houses of Congress, and to arguments by such individuals as have appeared voluntarily before them, usually as *ex parte* advocates of one system or the other. Very few of the members of such committees have been qualified by technical training and experience to pass on the complex issues thus presented, and until now no serious effort has been made to create a special tribunal of qualified experts to study and report upon the subject of our national weights and measures, and thus to provide a foundation on which Congress could construct legislation which would settle, wisely and permanently, this momentous question. In the hope of promoting the creation of such a tribunal, in order to point out its necessity and its great possibilities for usefulness, and to assist in an understanding of the issues involved, this paper has been prepared. The writer ventures to hope that the study of the subject during many years and an extended experience as an engineer and manufacturer may have given him some qualifications for the task.

A TECHNICAL COMMISSION

3 The argument herein advanced that a Technical Commission should be created to study and report upon the whole question of our Weights and Measures, its conclusions to form a foundation for action by the National Legislature, is justified by the example and experience of other nations.

4 France, suffering from the confusion of many divergent local systems, and after an agitation for *unification* dating from 1670, when Gabriel Mouton, a priest of the Church of St.Paul, at Lyons, published a book proposing a decimal system of measures based on a minute of the earth's circumference, adopted a decree, sanctioned by Louis XVI. on August 22, 1790, charging the Académie Française with the duty of determining "the scale of division which it believes most convenient for all weights, measures and coins;" and the Convention, on April 7, 1795, enacted a law, based on the recommendation of the Académie. confirmed and made effective by a later law of 1801, which embodied the metric system as it now exists, although many more laws were enacted and many years elapsed before the system was accepted by the French people for popular use.

5 Germany, suffering in like manner from different systems local to each of its many states, appointed a commission of scientists, which reported, in 1861, in favor of the metric system, which, however, was not adopted until after much further discussion, and the use of which did not become obligatory until January 1, 1872.

6 England, whose statutes show from early times a keen appreciation of the importance of fixing and maintaining standards of weights and measures, began in 1783, under the leadership of James Watt, to consider the question of reforming its system and of establishing an international system. The discussion thus opened was conducted in Parliament, by the Royal Society, and by other scientific and technical bodies, and has continued to the present time, but without resulting in any material change in the British system of weights and measures. In each of these three countries, and in others which have adopted the metric system, resort has been had to established scientific bodies, or to special technical commissions, for investigating the foundations on which to base constructive legislation.

7 In the United States, the Federal Constitution according to Art. 1, sec. 8, par. 5, gives to Congress the power, "To fix the standard of weights and measures," although, as pointed out by Hallock and Wade in their recent volume, "The Evolution of Weights and Measures," this is, "almost the only power expressly and specifically conferred on Congress, which that body has refrained from exercising down to the present time." The importance of the subject was recognized in various papers by Washington, Jefferson, Madison, and especially by John Quincy Adams. The *Report upon Weights and Measures*, submitted by the latter, February 22, 1821, while he was still Secretary of State, is a masterpiece which is still quoted in almost every discussion relating to the adoption of the metric system by the United States. Even prior to 1831, steps had been taken to insure conformity of the U. S. Standards with those of Great Britain and uniformity throughout the Union, and by 1856 the various States of the Union had been supplied with duplicate standards, thereby establishing that practical *uniformity* of weights and measures which prevails today throughout the United States. This is one of our best national assets, and in the extent of territory and population by which it is accepted, to the absolute exclusion in industry and commerce of every other system, it is practically without parallel in the history of the world. This system, it may be noted here, is also identical, except as to measures of *volume*, with that in use throughout the British empire. By an Act passed July 28, 1866, Congress provided that "it shall be lawful throughout the United States of America to

employ the weights and measures of the metric system." Although it has thus been lawful, for more than forty years, for any one who so desires to use the metric system of weights and measures in the United States, the people have not seen fit to avail themselves of the permission, but, in their industry and commerce, have adhered, with absolute uniformity, to their established standards. The question which now exists, in view of the persistent agitation for the compulsory use of the metric system, is confined practically to a decision as to which of the following possibilities can most wisely be accepted, viz:

a The retention of our present system unchanged.
b The retention of our present system, modified and improved in its details.
c The adoption of the metric system.

8 As to the *first* and *third* of these possibilities opinions differ, but the choice between them can readily and intelligently be made by each individual if called on to decide, for the alternatives they present are definite and well known, although the far-reaching effects of the change involved in the third may not yet fully be understood or appreciated, but as to the *second* no intelligent decision can be reached until the changes which it implies have been formulated into a definite plan, and this can only be done properly by a competent commission or tribunal, qualified for the serious technical and scientific work involved. Before we discard our present system which, even if not perfect, has served us well, let us have a clear understanding of the improvements and corrections of which it may admit, so that we may contrast it in perfected form with the other system which it is proposed to substitute for it.

9 Such a commission, if created, should be authorized to include in the scope of its work *all three* of the possibilities above defined, in order that each may be duly considered and weighed, and that the report of the commission, when completed, shall cover the whole ground, and shall serve not only as a basis for final legislation by Congress, but also, by its scope, thoroughness, and fairness, as a safe and competent basis for that public opinion which should underlie every statute, and without which no statute, even if enacted, permanently can endure.

10 And now, having thus outlined the situation and the subject, let us proceed to consider some of the underlying facts which it involves, especially those which relate to the relative merits of our present sys-

tem and of the metric system. The questions thus involved are so numerous, so important, and so distinct, as to make it expedient to discuss each of them separately.

DECIMAL NOTATION

11 In connection with any system of weights and measures the method of notation which may be adopted has two chief uses; namely, (1) in the daily life of the people, and (2) in the work of scientists, accountants, and others engaged in calculations. By a law of nature man resorts in the first instance to binary division, that is to division into halves, quarters, and so on. His next most usual resort is to duodecimal division. His final resort, but chiefly for purposes of computation, is to decimal division, the conveniences of which are artificial, not natural or inherent in the use of ten as a base.

12 The reasons for this sequence of preference are inherent in the law of numbers, and are not difficult to analyze. The most simple and most common division of anything is into two parts or halves. Its repetition produces quarters, eighths, sixteenths, etc. A child or a savage desiring to divide an article into parts resorts naturally to this process of binary division; we cannot imagine that he would ever resort to decimal division, the use of which implies a higher stage of arithmetical procedure. The duodecimal system is also, but in a higher sense, a natural one, because its base of 12 admits of division into aliquot parts by the divisors 2, 3, 4, and 6. Nature has divided the year into 12 months. Man almost universally divides the day into two halves and each of these into 12 parts of one hour each. Twelve multiplied by 5 produces 60, which is the universal base for the division of the circle, of the hour, and of the minute. The Latin word for one-twelfth, *uncia*, is the origin of our words inch and ounce, indicating, respectively, the one-twelfth part of the foot and the pound. Even in metric countries the *dozen* is a common unit of quantity for the uses of trade.

13 Decimal notation is based on count by the fingers, not on the law of numbers, hence, the form of the Roman numerals. Unlike 12, 10 is divisible into aliquot parts by only two divisors, 5 and 2; for all other subdivisions, resort must be had to fractions. The feature of the decimal system which gives it its great convenience, the raising of any digit to a higher power by placing behind it a cipher or another digit, thus changing its "decimal place," is not necessarily limited to the decimal system; it could be used equally and as readily in the duodecimal system, by adding (as was suggested long ago) two digits to our present nine, so that a change of position would raise the power of

the digit by 12 instead of by 10. As was pointed out by the late John W. Nystrom, a still better base for a new system of notation would be 16, which would involve the addition of six new digits. The decimal system, however, is too well established to make it at all probable that it will ever be abandoned for another having a base either of 12 or 16, great as are the advantages which either of these offer, and, therefore, we may conclude that it must be accepted as a finality. Granting this, the effort should be, in constructing or revising any system of weights and measures, to arrange it so that binary division shall be available for all the ordinary purposes of industry, trade, and the people, and the decimal system available for the uses of scientists, accountants, and in abstruse calculations of all kinds.

14 Granting that decimalization is thus desirable, it by no means follows that it is necessary to resort to the metric system to obtain it. Any unit, or base of measurement, can be multiplied or subdivided decimally. This is already done, to a large degree, with the English measures of length. Surveyors have long found it convenient to divide the foot into tenths, instead of into inches or twelfths, and the subdivisions of the inch into hundredths, thousandths, etc., is practically universal in connection with all mechanical work involving refined measurements. For the mere purpose of obtaining decimalization we have no need to resort to the metric system.

15 The tendency of binary division to persist, even where the decimal system prevails most largely, is found in France, where the common unit of weight, the half-kilogram, known universally as the "livre" (or pound), is divided, for all purposes of trade, into halves and quarters, and where also the subdivision of the millimeter (when expressed verbally, but not when written) is frequently into halves and quarters.

16 To sum up, therefore, the effort as to notation in constructing or reforming a system of weights and measures, should be so to arrange the various scales or "tables' as to facilitate the use of binary and duodecimal division for the every day uses of the people, and yet to facilitate also the use of the decimal system for all work of computation; as, for example, at present we divide the inch into halves, quarters, eighths, and sixteenths, etc., for common use and in talking, but into hundredths, thousandths, etc., for fine work and in writing.

17 Unquestionably there is a needless confusion in the English system of measures. We have, all told, ten tables of measures, nine of which are in active use. Three of these relate to *weight*, viz: troy weight and apothecaries' weight, in which, however, the same pound, ounce, and grain obtain; and avoirdupois weight, in which there is a

relationship to the others arising from the identity of the grain. It would seem to be a comparatively easy matter for a competent commission to reconstruct our system of weights, without necessarily changing its base unit, the grain, and in place of the threefold system we now have to substitute a single one, with decimal subdivisions if found expedient.

18 In the matter of measures of *volume*, we have "liquid measure," with a gallon of 231 cubic inches, "beer measure," with a gallon of 282 cubic inches (practically not used now), and "dry measure" in which the bushel, unfortunately, has a fractional relationship to the cubic inch. Now it would seem that possibly these three measures might be merged into one, and further might be so standardized as to conform to the British imperial measure of the bushel, which is slightly different from the American bushel, whereas the British pound, foot, and inch are identical with the American. With the slight change thus implied, the British and the American units of weight and of volume would be brought into perfect harmony, and could be simplified into practically two tables or scales, one for weight and the other for volume.

19 In measures of *dimension*, we have nominally four tables; "long measure," covering all measures of length, in which the English and American base is identical; "surveyors' measure," which is arbitrary, although based on the foot, the surveyors' chain being 66 feet in length; and "square measure," used for measuring surfaces of land and other areas. From square measure is derived our "cubic measure." In all of these, likewise, it would seem clear that something may be done in the way of simplifying the tables, discarding needless units, such as the furlong, rod, and rood, and reconstructing the scales to facilitate both binary and decimal subdivision.

20 No such changes, however, even where they do not affect the base of the system, should be adopted until, after exhaustive investigation, the effect of the proposed changes, *on all industries and interests concerned*, shall have been duly ascertained, nor until all interests which would be affected thereby have had due opportunity to submit their views and to explain the difficulties, if any, which they believe would arise from the proposed action. The issues thus involved are serious, numerous, complex, and highly technical. For their proper study, and for the selection of a new, or the development of an improved system which shall fully harmonize all difficulties and reasonably respect all interests, a commission is needed which should be composed of men of training, experience, and recognized authority

in all of the many lines of industry, commerce, and science which are involved.

21 In considering the question of reconstructing our present system as to each of the several scales or "tables" of weights and measures obviously the first step would consist in fixing the *unit* or base. This being determined, the next and final step would be to determine the multiples and submultiples of the base which may be convenient or necessary, and in determining these to aim to make available the system of binary notation for common use and a system of decimal notation for purpose of computation.

ABSOLUTE UNITS

22 The early units of measurement were usually based on nature, as for example, the foot, the thumb, a grain of barley, etc. Each country or district fixed its own units. Commerce was restricted and chiefly local. Divergence in weights and measures was thus of little consequence at first, but became more serious as industry developed and as commerce broadened and became international. Hence arose suggestions for the fixing of local and national standards, and finally for the creation of standards which should become international. The underlying motive throughout was a growing perception of the importance of *uniformity*, in place of the endless diversity which prevailed.

23 France, afflicted by a chaos of divergent local units, took the lead in the movement for uniformity during the period of its revolutionary upheaval, when idealism was rampant and at a time when modern industry was still unborn. It appointed a commission of scientists, in 1790, whose work culminated in the metric system, which was nominally put into effect in 1801. Many of the original features of the metric system were fanciful, impracticable, and were soon abandoned, as for example, the decimal division of the year, the month, and the day; of the quadrant, and of the circle. Even the base of the system, intended to be founded on nature and in the fixing of which infinite care was taken, was ultimately found to be erroneous. It is recognized now, however, that this fact is immaterial, that the meter is none the less an effective base for a system of weights and measures, because it is not an exact part of a meridian, and that the prime essential in any system is to have a base which is definitely determined and which shall not be changed. The metric system, as a whole, is logical, consistent, and has proved satisfactory for most uses, especially in abstract science. It has not proved entirely satisfactory in applied science, notably in the metal-working

and textile industries, but this is not surprising as these were in their infancy when the metric system was devised, and as no one representing them had any share in its devising.

24 What France chiefly needed and sought was *uniformity*, as is shown by the decree sanctioned August 22, 1790, which reads, "the National Assembly, desiring that all France should forever enjoy all the advantages which will result from uniformity in weights and measures, etc., etc." What France sought was thus *national unity* in her weights and measures. In accomplishing this, she sought also good units or bases for her new system of weights and measures.

25 Germany, also in chaotic condition, each of its 40 States having its own standards, followed the example of France by the appointment of a commission, in 1860, and by the adoption, in 1871, of the metric system. What Germany sought was likewise *national unity*, that is,uniformity of weights and measures throughout her boundaries. With the metric system already created, and proved by experience to be sound and satisfactory, and with that system already in use by France, her neighbor on the west and in many ways her most important competitor, she wisely decided to adopt the metric system rather than to create a new one of her own, and thereby to secure not only national, but also partly international unity. Practically like conditions have existed in the case of each of the so-called "metric countries," that is, those which have adopted, officially at least, the metric system. The primary motive has been to substitute fixed standards and uniformity for uncertain standards and diversity. *Finding the need of a change*, they have wisely availed themselves of the metric system, scientifically constructed, successfully tested, and already adopted by many other countries. This is emphasized by Hallock and Wade, who say (p. 82): "When we join to these considerations the fact that the separate systems in nearly all cases were illogical, inconvenient, and lacking in uniformity and facility of use, we have the explanation of the eventual spread of the metric system in Europe."

26 In the case of the United States, however, no such impelling necessity exists. As previously stated, we now possess *fixed standards* and *national unity*. In other words, we already have those blessings the want of which has led other nations to adopt new standards. Still more, we have also international unity (except as to measures of volume) with the whole of the British Empire, with commercial China and with many other countries, and as to measures of *length* with the Russian Empire, all of which we would sacrifice, temporarily if not permanently, in case we should abandon our present system.

27 Now, are the French, or metric units, better than ours, and if so, are they sufficiently better to justify the rejection of the latter in their favor? As stated by John Quincy Adams in his ever memorable report of 1821, on the question of adhering to our present system or adopting the metric system, "The first position which occurs as unquestionable is, that change, being itself diversity and, therefore, the opposite of uniformity, cannot be a means of obtaining it, unless some great and transcendent superiority should demonstrably belong to the new system to be adopted, over the old one to be relinquished."

28 As to Length. The meter has been found to be too long a unit for most industries, except the textile, in which it and the inch both prevail. The millimeter is too short for ordinary measurements, and too long for fine ones; the inch and its decimal divisions are better, while in the building trades the foot is preferable to the meter. The kilometer is good, but not better than the mile, to which its ratio is .62137.

29 As to Weight. The kilogram is about double the pound, and experience has proven that it is a less convenient unit than the latter. For the common uses of the people the French discard the kilogram, taking its half part, which they call call a "livre," or pound, and which they then divide into halves and quarters. The gramme is equal to 15.432 grains and, with its subdivisions, probably a better unit than the grain. The tonne is practically identical with our ton of 2240 pounds, its ratio to the latter being 1.016.

30 As to Volume. The liter is almost identical with our quart. Our larger unit, the gallon, is perhaps more convenient for many uses, but either is good. The hektoliter is equal to 2.8375 bushels and would seem to be too large, although its tenth part coincides closely with our peck.

31 As to Area. The hectare is equal to 2.471 acres. As a unit, this is too large and the acre is better.

32 Certainly this comparison fails to show any marked preponderance in favor of the metric units; if anything, it would rather prove the reverse.

33 It is conceded that in their *inter-relations* the metric units have a marked advantage, and constitute collectively a more scientific and logical series than exists in any other system. This fact, however, while of great interest to scientists and of great practical benefit in their work, does not interest the common people, has no bearing upon the transactions of their daily life, and does not constitute any just ground for attempting to force upon them new units which, for

their uses, are less convenient than those they now have, especially if this change would carry with it little or no compensating gain.

34 This argument against a change in the basic units by no means implies, however, a corresponding objection to a revision of the scales or tables which embody the multiples and submultiples of the basic units. It is conceded that these tables, as they exist in the English system of weights and measures, are needlessly complex and numerous, and could easily be simplified, to their great improvement, without at all disturbing or changing any of the basic units. But this is a totally different proposition from a change in the basic units. It would involve no change in habits of thought, and little or no change in the mode of expressing the daily transactions of the people, whereas a change of *units* would be subversive of both and of all records and expressions used in the current transactions of life as to everything in which our weights and measures are involved.

35 The utter failure, which commonly prevails, to realize what such a change would mean was shown by Mr. Littauer, the author of the latest bill in Congress for the adoption of the metric system, who, in his testimony before the House Committee on Coinage, Weights, and Measures, March 22, 1905, said, "Of our 80 millions people, 70 millions would learn such measures (of the metric system) as they would need probably within a day or two." Such a statement is pure empiricism, opposed by all experience of the past, and disclosing complete ignorance of the subject. As a contrast of experience with empiricism, may be cited the statement of Major F. A. Mahan, U. S. A., a prometric advocate, who admits that, although he has "employed the metric system largely for 30 years," he has always "experienced difficulty in *thinking* in the system." That is, he has had to translate from the metric system into the system with which he has been familiar from childhood.

36 So far, therefore, as the question of absolute units is concerned it has not been shown that those of the metric system, the meter, the kilogram, the liter, etc., have any inherent superiority to those of the British and American system, the foot, the pound, and the quart (or gallon), sufficient to constitute a reason for the abandonment of our established units in favor of those of the metric system.

MEASURES OF LENGTH

37 Between measures of length and measures of all other kinds there is an organic difference which it is of vital importance should fully be recognized in the consideration of the subject under discussion.

38 Measures of value, weight, and capacity are used chiefly in commerce and the transactions of daily life, all of which are transient; but measures of length relate chiefly to applied science; that is, to organized industry, the transactions and results of which are not transient but more or less permanent. In the expressive phrase of Mr. Henry D. Sharpe, they are, "linked irrevocably to the past," They *exist*, they are imperishable, and many of them never will nor can be changed so long as the things to which they apply shall endure.. Among those thus referred to, may be specified the following:

All existing structures.
All existing machines.
All existing railroad equipment.
All existing interchangeable parts, such as screws, nuts, piping, shafting, couplings, etc.
All the existing vast equipment of special tools, gages, etc., of the metal-working industries.
All existing land areas and titles.

39 To change the monetary unit of a country involves some temporary inconvenience, but no permanent or serious disturbance. Transactions in money relate chiefly to the present, or to the immediate past. A change of this kind has successfully and easily been made, within the past century, by nearly all of the chief commercial nations.

40 To change the unit of weight would also involve some temporary inconvenience but nothing more, with the important exception of technical records and scientific work. Outside of these latter, transactions involving weight are matters chiefly of the present or of the immediate past. The same is true of the unit of volume or bulk.

41 But for us to change our unit of length would be to undermine the whole fabric of our vast mechanical industries, to disorganize our technical science, and to cause an actual destruction of values and of vested rights which would be colossal in its extent and almost infinite in its effects. The reasons for this are overwhelming; they are already abundantly on record, and will be referred to later. The variation in length of the British yard has been "scarcely more than a hundredth of an inch" *in the last four hundred years*.

42 Why should this revolutionary and destructive change be made? Who urges it? Not the interests chiefly and directly concerned, and which would have to foot the bill—the organized industries of the country—but theorists and scientists, sincere beyond doubt, but without practical experience in the matters chiefly involved, on whom none of the vast loss would fall. Possibly the ultimate bene-

fit of the change which they urge might be so great and far reaching as to outweigh the enormous waste and loss which certainly would be entailed, but neither of the groups so aligned on opposite sides in this controversy is competent alone to weigh the evidence and to settle this question. Each is prejudiced, and their interests are opposed. Calm, thorough, and skilful investigation of the whole vast subject, by an impartial technical commission, is the only possible way by which to reach a decision which shall be sound and just to all interests, and which will stand the supreme test of experience and time.

43 Since 1866 the use of the metric system has been legal in the United States. Any manufacturer who so chose has been free to use it. With insignificant exceptions none have chosen to do so—they do not want it—and yet theorists and scientists, who find it useful in *their* work, would force its use on others who have neither the need nor the desire for it, and who believe that its enforced employment would be a vast and lasting injury to them. Legislation of this character would be paternalism run mad. Our laws should be made *by* the people, not *for* them.

44 Those who seek to change our unit of length by arbitrary legislation, which would substitute the metric system for our present system, have thus far attempted only to secure a law which would make the use of the metric system compulsory in the transactions of the Government, but the author of the latest of these proposed laws, Mr. Littauer, in his testimony concerning it before the House Committee on Coinage, Weights, and Measures, said frankly, "I hope it will be the entering wedge towards the adoption of the metric system generally." This is the avowed end in view with all pro-metric advocates who have honestly expressed themselves, and, therefore, may fairly be assumed as the ultimate purpose of their efforts. I repeat that legislation of such vast importance, and such far reaching effect, should be based on the most careful and competent expert investigation, and upon an unmistakable popular demand. ***No such demand exists.***

45 The transition from our actual system to the metric basis, in measures of length, might have been comparatively easy one hundred years ago, when modern industry was just starting upon its marvelous career, but would be infinitely difficult now in view of the vast present development of that industry, nearly every implement of which is based upon our established unit of length. In France even now, after more than one hundred years, some of the old units of length still persist, especially in the textile industries, as shown conclusively by Mr. Dale. In Germany, after forty years, this is also true and in a greater degree. Mr. Henry Hess, of the German Niles Tool Works,

Berlin, says (1902): "The Rhenish inch is nearly universally used in the building trades." a statement which the writer verified in 1903. France adopted the metric system in 1801, and Germany in 1871. If the United States should adopt it in 1906 how many years, how many *generations*, would have to elapse before our present standards of length, the foot and the inch, would disappear and be replaced completely by the meter? So long as they might persist, we would have confusion where we now have absolute unity. Surely the endorsement of a competent technical commission should precede any serious action in the direction of such a change. The manufacturing industries of the United States and Great Britain combined have far more capital invested in plant, machinery, and implements based on the English inch than have the corresponding industries of all the so-called metric countries based on the meter. The units of weight and of volume may be changed without great or lasting disturbance of those industries, but not the unit of length.

46 To change the unit of length would be to substitute variety and confusion where now we have absolute uniformity throughout the Anglo-Saxon world. Whatever may be the plea of the scientists in this regard, that of the manufacturers may be summed up in four words, "Let us have peace." As is well said by Hallock and Wade, (p. 174) "it remains for the adherents of the metric system to convince the manufacturing public by demonstrating its (the metric system) superiority for their work."

UNIFORMITY

47 The chief and strongest argument of those who advocate the adoption of the metric system is that thereby we shall attain to greater uniformity than we now have, because thereby we shall conform our practice to that of the countries which have adopted, successfully and completely, the metric system. Let us see what are the facts under this head.

48 *No country in the world*, except the United States and the British Empire, now has complete uniformity in its weights and measures. In nearly all of the so-called metric countries the old measures are the measures of the people, and the metric system is used only by the government, by scientists and in commercial transactions of the larger kinds. In the United States and the British Empire, on the contrary, absolute uniformity as to all weights and measures exists throughout each, and is international between them except only as to measures of volume, that is, the bushel, and the gallon, in which unfortunately, small differences exist between the two standards.

Should we adopt the metric system, even for Government use only, thereby we would destroy our present uniformity and would inaugurate confusion. Says Mr. Adams, "Is your object *uniformity*? Then, before you change any part of your system, such as it is, compare the uniformity that you must lose, with the uniformity that you may gain, by the alteration."

49 In confirmation of this argument, the following figures are submitted showing the relation of population to manufacturing industries in the chief industrial countries of the world.

	Population Millions	Total Mftrs. Millions
United States	82,6	$7,022
Great Britain	43,5	3,990
British Colonies (except India)	23,9	?
Group A	150,0	11,012
Per capita		$73.
France	39,0	2,360
Germany	56,4	2,837
Group B	95,4	5,197
Per capita		$54.
Austro-Hungary	48,6	Figures lacking, but if $54 per capita, a most liberal and probably an excessive assumption, they would aggregate $5,810
Italy	33,2	
Belgium	7,0	
Scandinavia	10,1	
Holland	5,4	
Switzerland	3,3	
Group C	107,6	$5,810
Then, totals of Groups B and C would be	293,0	11,007

Thus, while groups B and C combined show a greater total of population than group A in value of manufactures they barely equal it.

50 The adoption of the metric system by other countries is no proof of its inherent soundness or merit, but only of a desire to secure the possession of one or more of three obvious *desiderata*, viz:

a Fixed standards of weight, volume, and length.

b National uniformity as to these standards.

c International uniformity as to these standards.

51 Naturally and usually the smaller states, in adopting new standards have adopted those of the larger states, especially if con-

tiguous, as for example, Canada has adopted and uses the American dollar as its monetary standard. The larger nations which have found it desirable to change their standards have done so, in every case without exception, primarily to obtain *uniformity* in place of a chaos previously existing, and, being continental nations, have wisely adopted the metric system, previously devised and brought into effective practice by France, rather than the British system, or than evolve a new and origina' system of their own. But neither the United States nor Great Britain has any such need or motive for change. Each already has that which other countries chiefly sought in making the change, *uniformity*, and by changing they would lose it.

52 The argument is made that out of thirty-nine so-called "civilized" nations, thirty-six have adopted the metric system (although most of them for Government purposes only), the remaining three being the United States, Great Britain, and Russia. In reply it may be pointed out that the combined population of the three latter countries is 567,000,000 and of the remaining thirty-six countries only 445,296,000. A larger population exists within a radius of fifty miles from the Town Hall of Manchester, England, than in any one of the first twenty-five of the thirty-six nations referred to, and the combined population of twenty-four of them is only equal to that of the United States.

53 Measured either by industry or by commerce, the English units of measurement are in use today at least as extensively, and probably much more so, than those of the metric system. Measured by colonizing and assimilating power, the Anglo-Saxon race, which uses the pound, gallon, and foot as its standards of measurement, far outranks all the countries which use as their standards the kilogram, liter, and meter, combined. To the former already belongs the premiership in trade, in influence, and in control of the undeveloped and backward races of the world, having a combined population of over 600,000,000, not counting any of the so-called "Latin" countries, Russia, or the subordinate States of European powers.

54 We now *have* uniformity. Should we not hold it as a priceless treasure?

INFLUENCE ON DOMESTIC OPERATIONS

55 As pointed out before, the transition from our present system to a new one would be relatively simple and easy as to measures of weight and volume, but not so as to measures of length and area. As to each there would be inevitably a period of confusion while the people were learning the names and beginning to learn the values of

the new units, but in time they would acquire and use the new system. In matters involving measures of length and of area, however, a far greater obstacle would have to be overcome, namely, the difficulty of effecting the transition from the old to the new basis. The old units would *exist* in every machine, in every structure, and in innumerable articles of daily use, and no matter how superior the new system might be to the old, the impossibility of immediately bridging the gulf between the two would remain.

56 What advantage in our domestic industry and trade could be expected from the substitution of the metric for our present system? As shown above, the metric units as a whole are no better than ours, and those relating to length and area are inferior. The law of 1866 legalized the use of the metric system, and those who prefer it are already at liberty to use it. What is there in the existing situation to justify further legislation intended to make the use of the metric system *compulsory* on the Government as an entering wedge for the avowed purpose of ultimately forcing its use upon the people? A law so revolutionary in its character should only be enacted in response to a clear, if not an overwhelming, public demand. No evidence is adduced to show that any such demand exists. As has well been said by Mr. J. E. Hilgard, of the U. S. Survey, "It has ever been the practice of the Anglo-Saxon people to make laws in conformity with customs, not to create customs by compulsory laws."

57 Although the manufacturers of the United States were authorized in 1866 (since which date their collective export business has enormously increased), to use the metric system, not one in ten thousand has found it necessary or even expedient to do so, and if appealed to they would oppose overwhelmingly a proposition to coerce them in this respect. On the other hand scientists, chemists, and, to a certain extent, electricians, opticians, and others, have found it convenient to use the metric system, and increasingly are availing of it in their work. Each group knows its own needs best, but neither should seek to coerce the other.

58 If we should adopt the metric system our old units would persist for generations. This is the case in France, after one hundred years and in Germany after forty years, although in these cases the change was made when modern industry was in its infancy or comparatively undeveloped. People *think* in their units of measurement and cannot translate mentally into strange units, especially in the transactions of daily life. The difficulty thus implied indicated by the mere statement of the exact metric equivalents for a few of our familiar units, *e. g.*,

A two-cent postage stamp equals in value 0.10336 franc.
1 mile equals 1.60934 kilometer.
1 pound equals .45359 kilogramme.
1 quart equals .94636 liter.

How long would it be before any of us could *think* in these unfamiliar units, or use them correctly without constant reference to the tables of equivalents?

59 Even metric advocates admit that we could not change our system of land measurements; that the acre as the basis of land records would have to be maintained. Their belief is justified by the experience of certain of our southwestern States, where French and Spanish units persist in transactions relating to land, and by the familiar fact that certain old records in Philadelphia, based on the accident of an inaccurate surveyor's chain, are still maintained. But these admissions imply that the adoption of the metric system would involve not unity but a *dual system*; confusion in place of order.

60 The same argument applies in the vitally important matter of screw threads. *These underlie almost every mechanical industry*, and are almost as impossible to change as land areas. Two systems of screw threads now dominate the mechanical world, the United States or Sellers, and the British or Whitworth. A feeble effort has been made to promote the adoption of a third, a metric system of screw threads (proposed at Zurich, in October, 1898), but even in metric countries the use of one or both of the other systems prevails today.

61 In the metal working industries a vast investment has been made in special tools, implements, and gages for the economical production of work on the interchangeable basis, all of which are based absolutely on the English inch as the unit of length. Only an insignificant part of this equipment could be converted to the metric basis. If the latter prevailed, this vast equipment would need to be duplicated to conform to the changed dimensions of the product. Pro-metric advocates, unskilled in the art, allege that all that would be needed would be to redesignate, in metric terms, each old article, without changing its dimensions. Those who know best will realize the unsoundness of this argument. For example, the actual dimension of a certain part of the well known Yale lock is .51 inch, and the permissible variation from this standard in either direction is one one-thousandth inch. The metric equivalent of .51 inch is 12.954 millimeters. Obviously the latter would be an inconvenient and almost unworkable dimension to maintain; obviously it would be desirable to change it to 13 millimeters. But this would be an enlargement of almost two one-thousandths of an inch, which is inadmissible. The old size

would persist, or if discarded, new tools and gages would be required. Millions of similar examples would be brought to light by due investigation. As stated by the writer, when a witness at one of the recent hearings before the House Committee on Coinage, Weights and Measures, 'One thousand millions of dollars would not cover the ultimate cost to the manufacturers of the United States of the compulsory adoption of the metric system in the resulting changes in their equipment of machinery, tools and gages.' It would hardly be an exaggeration to state that in some cases such an enforced change would mean bankruptcy to the manufacturer. Dr. Coleman Sellers has testified that the cost would approximate two hundred dollars per employé. Mr. Tannett-Walker of Leeds, England, places it at fifty to seventy dollars per employé. Mr. McFarland, Vice President of the Westinghouse Electric and Manufacturing Company, places the amount, for their Pittsburg works only, at $650,000. If the number of employés in the metal working and allied trades be assumed to be only 5,000,000, and the cost per employé only $100, the aggregate would be $500,000,000. And yet, Mr. Littauer (author of the last pro-metric bill) *thinks* the cost might amount to $1,500,000!

62 France, in 1801, had no such conditions to deal with, nor did Germany even in 1871. Modern industry, especially in the United States, is largely the creation of the last fifty years. What might have been easy in 1801, or feasible in 1871, has become almost impossible in 1906. The proposed change would vitiate all existing Anglo-Saxon engineering literature. The thousands of engineering formulae and multitudes of tables, and the vast records of past experience, are all stated in terms of our existing standards. All would have to be rewritten and translated into unfamiliar terms to make them available for use in practice in which the metric system would form the working basis. But engineers, and all other designers and constructors, *think* in their established units of measurement. They cannot think in others which are unfamiliar, but can only translate from the former to the latter, at great cost of time and trouble, and with still greater risk of error. On this point we may quote a pro-metric writer in "Science" for August 5, 1904, who frankly admits that "Reasonably complete assimilation will take several generations . . . . none of us will live to see any better than good progress on the part of the public." So also Mr. E. R. Briggs, of Rugby, England, a pro-metric advocate, who has long used the metric system in his own work, in a paper read October 6, 1905, admits that, "It may be taken for granted that the end of ten years, nay one hundred years, would still see the existence of the Imperial (British) system." Surely on the facts thus

disclosed the endorsement of a competent technical commission, based on an elaborate and impartial investigation of all the facts, should precede any proposal for the compulsory adoption of the metric system in the United States. Such a commission could also properly give due consideration to the argument, so frequently made but as often disputed, that the adoption of a decimal system, in place of our present mixed system of weights and measures, would result in a large saving of time now wasted, both in school and subsequently in the actual transactions of commerce and industry.

INFLUENCE ON FOREIGN OPERATIONS

63 It is urged, as a *chief argument* in favor of the metric system, that it would promote our export trade. If true, this is an important factor which should have due weight, but is it true? For reply we can only look to experience. What does this teach? Has the non-use of the metric system retarded the growth of our exports of manufactures? In 1895 they were $40,000,000 or 12.76 per cent of total exports; in 1905 they were $543,000,000 or 36.44 per cent of total exports. During this period of ten years our exports of manufactures increased thirteenfold, and their percentage of our total exports increased threefold. Would these increments have been greater or more startling had we adopted the metric system?

64 Has the non-use of English measures by France, Germany and other metric countries operated to decrease our imports of manufactures from such countries? If they should abandon the metric system tomorrow, and substitute for it the British-American system, would our purchases of their manufactures thereby be increased?

65 As a matter of fact there is no recognized or visible demand from our export merchants, or from the foreign merchants to whom they sell, that we should discard our present system of weights and measures and adopt the metric system. As has well been stated by Mr. J. E. Hilgard, of the U. S. Coast Survey. "Until all nations use the same language and the same money but little is gained in the way of unification of values by making the units of weight and dimensions alike." And another writer, Mr. G. W. Colles, makes the following pertinent observations, "While other nations, anxious to gain perfection at a stride, have hurried from one expedient to another, the steady plodding of the Anglo-Saxon race has placed them far in the lead among commercial nations; and rendered it self-evident that, so far as *language* is concerned, notwithstanding any theoretical advantages which others may claim, and the scorn which may be offered to its uncouth spelling and illogical pronunciation, if any one language

is ever destined to supplant all others, the English must be the one. And if the same supremacy which has followed the English language and other institutions does not follow also their system of weighing and measuring, it is at least much too early to predict it of any other." (Transactions of the A. S. M. E. 1896, p. 528.)

66 In this connection the figures in the following table are pertinent.

FOREIGN TRADE OF THE UNITED STATES, FOR THE YEAR ENDING JUNE 30, 1905

IN MILLIONS OF DOLLARS

	Exports	Imports
Total foreign trade	1,518	1,117
Great Britain and British Empire	741	330
Ratio to total	49%	29%
British Empire, China and Russia	820	370
Ratio to total	54%	33%
All other countries	698	747
Ratio to total	46%	67%

67 The above figures show clearly the preponderance of value to the United States of our export trade to Great Britain and her colonies over that to all other countries of the world, and the British markets are usually superior to others for manufactures of the medium and higher grade, in which we chiefly excel. China is our best customer for textiles, and in 1905 bought them to the value of $33,849,717.

68 The writer, speaking from personal experience in the export of certain American products to all parts of the world, can state that during more than thirty years of such experience no instance has occurred in which our use of English units has interfered in the slightest degree with such business, nor in which any demand has been made for the employment in such business of the metric system. It is his conviction that our adoption of the metric system would not perceptibly increase our exports to metric countries and that it would handicap our export trade to other countries which offer us the largest markets. So long as England maintains her present standards we would need to maintain our existing units of measurement, wholly or in part, for all goods made for British markets, which, as shown in the foregoing table, constitute 49 per cent of the total. This would intensify and prolong the persistence of our old units, and would retard immensely the acceptance and use of the metric units. The result would be little or no gain to our export trade to metric countries, some damage to our trade in British countries, and a great increase of

confusion from the loss of that perfect uniformity which now prevails in our weights and measures.

69 Surely in this respect, also, the findings of a competent commission, based on a thorough investigation of all the many branches of industry and commerce which are concerned, should precede any alteration of our present system of weights and measures.

INFLUENCE ON GOVERNMENT OPERATIONS

70 No effective argument has yet been offered that the government would, in any way, directly or indirectly, be benefited by the adoption of the metric system. Mr. Littauer, the author of the latest metric Bill in Congress, in urging its passage, said, March 22, 1905: "The only object in making it compulsory on the Government (to use the metric system) is that the people throughout the United States may begin to get some practical experience of the metric system, in order that they may determine, at some future day, whether or not they will demand its compulsory use throughout the country." Is there an overwhelming demand by "the people" for any such paternal action by the Government? Are they so dissatisfied with their present right to use the metric system, and their present liberty to use either system, that they demand to be restrained from using the one and coerced into using the other, even in their transactions with the National Government? Absolutely no proof of any such demand is offered. Heretofore, "the people" have regarded this question as academic, rather than practical, and simply have not been interested. If the danger of coercion should become real, they may be depended on to speak and in no uncertain terms.

71 Plainly stated, the recent Bills for the compulsory use of the metric system are intended by their authors to educate the people to understand what they should, but do not, desire. Is this a proper function of our Government? Certainly it is not government by representation, for no member of Congress has ever yet had any mandate from a majority or even from an appreciable minority of his constituents to propose, still less to promote, such a law.

72 Has any other great country ever changed its system of weights and measures, or even forced its officials to use alien standards, simply by legislative enactment not based on previous thorough investigation by some technical commission or other expert body? France, under Louis XVI., in 1790, through the National Academy, appointed a large commission of the most distinguished scientists, among them Lagrange, Laplace, Condorcet and Lavoisier, who, taking eleven years, reported finally in 1801. Germany, in 1860, appointed a tech-

nical commission, whose work also occupied eleven years, and was completed in 1871. Shall we, with no such chaotic conditions to justify a change as confronted them, ignore their example and attempt this momentous change by a simple act of Congress, without any scientific and expert previous investigation? Such a proposition implies an utter want of understanding of what such a change would mean, and the complete disjointing of our industries which would follow. Where is the resulting benefit, or what the excuse, to justify such precipitate and informal procedure in a matter of such vital and lasting importance?

73 Turning now to the effects of such a change on the business transactions of the Government itself, the following may be pointed out as conditions which should at least be studied carefully before we commit ourselves to such a momentous change, viz:

a It would disqualify for a long time probably 95 per cent of the present army of Government clerks from doing their work efficiently.

b It would for many years add greatly to the time and cost of all government accounting, and to the army of Government employés.

c It would greatly increase the tendency to error.

d It would make the Government reports for a long time unintelligible to the people.

e It would preclude comparison of past with future records and statistics.

f It would preclude ready comparison of our statistics with those of the British Empire.

g It would make void the engineering and technical formulæ which our Government engineers (Army and Navy), naval constructors, architects, etc., have used all their lives.

h It would compel the Government or the seller, in every transaction, so long as the metric system was used by the Government only, to express every detail of such transaction in terms of both systems.

i It would compel the Government, in order to obtain commercial products, to describe them in alien terms but in intermidable fractions, *e. g*;

A bar of 1 in. iron as 25.4 millimeters;

A $\frac{7}{8}$ in. bolt as 22.225 millimeters;

A 12 in. plank as 304.8 millimeters, or as 0.3048 meters;

A ton of coal as 1.016 tonne;

A gallon of oil as 3.785 liters, etc.

j It would cause the small manufacturer and dealer to reject Government business.

k It would increase the trouble and cost of doing all business with the Government.

l It would create confusion and disorder where we now have uniformity and order.

m It would change the readings of all coast survey charts.

n It would compel an entire revision of the terms used in Dingley Tariff Bill.

74 Surely these vast changes, affecting the work of every department of the Government, and every detail of that work, should most carefully be considered and reported on by a competent commission before we commit ourselves to the compulsory adoption of the metric system, even for use by the Government only.

CONCLUSIONS

75 In summing up the conclusions to be deduced from the preceding arguments, we cannot do better than to quote the warning of John Quincy Adams, in his report of 1821, "If there be one conclusion more clear than another, deducible from all the history of mankind, it is the danger of hasty and inconsiderate legislation upon weights and measures." To this may properly be added a quotation from a paper submitted to the December, 1896, meeting of The American Society of Mechanical Engineers, by Mr. George W. Colles, as follows: "If there is to be a compulsory law of any kind, let it be one compelling the national legislature to leave this matter alone until we can have it decided by a competent and practical commission, appointed from the people."

76 And, again, a Select Committee, appointed by the Parliament of Great Britain, reporting in 1862 in favor of the metric system, added that "No compulsory measures shall be resorted to until they are sanctioned by the *general conviction of the public.*"

77 One Congressional committee after another has considered this problem and attempted, in good faith but unsuccessfully, to solve it, each of them failing to realize that its essentially technical and many-sided character precludes effective action by a political committee, however talented and earnest its members, and that an essential preliminary to safe action by Congress or any of its committees is an impartial and exhaustive investigation of all the many issues involved by a technical commission, representative of all the great inter-

involved, and unstinted as to time and opportunity, whose report shall serve as a basis for constructive legislation.

78 If such a commission is created its members should approach their work with open minds, unprejudiced and untrammeled, solicitous only of learning all the facts, of weighing all arguments, of hearing all interests, and of reaching conclusions which shall be sane, just, sound, and permanently right. Hitherto, the discussions have lacked that judicial atmosphere which their topic and their importance demand; have been too partisan in character and too narrow in scope. On the one hand the advocates of the metric system have sought to make its use compulsory at once by the Government and ultimately by the people, while on the other hand those who believe such a change would be unwise, and especially those who think their property rights would be injured by it, have been put to much trouble and some expense to defeat the efforts of the pro-metricists. Neither the proponents nor the opponents of the metric system are infallible, obviously both are prejudiced and each precommitted to one view of the case, and clearly the decision cannot be left to them. In the light of our own experience, and that of foreign nations, it seems equally clear that no legislative body, not even the Congress of the United States, can wisely undertake to deal with a subject so technical and so interwoven with all science, industry, and commerce, unaided by technical advice and by previous expert investigation; and, therefore, that we should now follow the precedent established by each of the great nations which has acted in this matter by creating a Technical Commission to which it shall be referred for investigation and report. In support of this view the writer frankly admits that the longer he studies this question, and the more he grasps its importance and its relation to all the varied activities of our people, the more he realizes that no individual alone is competent to deal with it, and that a safe and enduring solution of it demands the combined labor and intelligence of many minds, each qualified by previous special training and experience in science, industry, agriculture, and commerce, whose united judgment shall recognize, respect, and conserve all of the varied interests concerned.

79 While thus admitting the impropriety of deducing, from any investigation and presentation of the facts which has yet been made, conclusions as to what changes, if any, in our system of weights and measures are expedient and desirable, and while frankly avowing that his study of the subject thus far has led him to question the expediency of our substituting the metric system for our present system of weights and measures, and to believe that a better solution may

perhaps consist in reforming and simplifying the latter, with few if any changes in its basic units, the writer submits the following conclusions as justified by such facts as have herein been presented, viz:

80 Decimal Notation. The advantages of a decimal system are conceded for purposes of computation, but denied for the ordinary uses of the people. For the latter binary division always has and always will prevail. Decimal notation is feasible with any system. If finally we decide not to adopt the metric system, let us then reform our scales or tables, and in so doing decimalize them so far as found expedient.

81 Absolute Units. The metric units are no better than, if as good as, the units of the British-American system, and are equally arbitrary. The most important metric unit, that of length, is inconvenient. What is essentia' is that the units shall be definite and fixed. Next to this in desirability is that they shall be such that binary division shall be available for common uses, and decimal division for purposes of computation. The metric system fails to meet this requirement.

82 Measures of Length. These are organic, and are "linked irrevocably to the past." Many of them practically are immutable, such as those relating to land ownership, to construction, to screws, to interchangeable couplings, etc. Without great difficulty, we may change our units of weight and of volume, but not those of length or of area. To attempt to change the latter would entail vast losses, and would bring no compensating gain. The metric system is now legal in the United States, and yet unused. Of the organized bodies which have voted on this question, forty-four are on record as opposed to the adoption of the metric system in the United States, as against fourteen in its favor. The adoption of the metric system would mean, for a century at least, that we would have *two* systems of weights and measures where now we have only one. In reply to the argument for a change the plea of organized industry is, "Let us have peace."

83 Uniformity. We now have absolute national uniformity, and, except as to measures of volume, international uniformity with the British Empire. No other nation in the world, save Great Britain, enjoys today such absolute uniformity as to weights and measures as the United States. We may change our *scales*, if we retain our present base units, without losing this national blessing, but if we change our *units* of weights and measures, we shall substitute, for a hundred years or longer, confusion in place of the absolute unity we now enjoy. Other countries have changed their system to secure uni-

formity; we now have uniformity but would lose it if we should change our system. Let us make sure that the benefits to be secured by change would outweigh the difficulties and objections which any change of units implies, or else let us keep our present units.

84 Influence on Domestic Operations. The law of 1866, which legalized the use of the metric system, is all that is now justified; any further legislation would imply coercion, and this is contrary to the spirit of our laws. American manufacturers are free today to use the metric system but do not employ it, nor do they wish to be coerced into so doing. American scientists are equally free today to use the metric system, and are doing so. Let each respect the rights and interests of the other. No public demand for a change exists, and without it the change should not be made. The change, if made and if enforced, ultimately would involve a loss or injury to American manufacturers of probably more than $1,000,000,000, with no compensating benefit which they can perceive. The old units would persist in popular use for one hundred years or longer, during all of which time we would have confusion where we now have unity.

85 Influence on Foreign Operations. The enforced adoption of the metric system would not assist our export trade, but more probably would hinder it. Available statistics do not show that the non-use of the metric system has retarded our exports of American manufactures, nor that the use of the metric system in foreign countries has decreased our imports of manufactures from such countries. No demand for the change has been made by our export merchants. Of our export trade in 1905, 49 per cent was with the British Empire, and in this trade the adoption of the metric system, if of any influence, would be harmful, not helpful. The net result of the change would be increased confusion, without any compensating gain.

86 Influence on Government Operations. The proposed change would greatly increase the operating expenses of all departments of the government, would almost destroy the value of government statistics for popular use, and would bring no compensating benefit of any kind. It would substitute confusion for the perfect uniformity which now prevails. Save the plea that it would give the people a basis of experience on which later to make a final decision, the proposal to *compel* the use of the metric system in all Government work has no argument to its credit, all of the arguments appearing on the debit side of the account. If investigation by a competent commission shall prove the contrary the change may be justified, but until then we should hold fast to the national unity which we now enjoy in our weights and measures.

REFORM

87 The opponents of the adoption of the metric system in the United States frankly admit the existence of many imperfections in our present system of weights and measures, but point out that these are not inherent in the *units* of the system, but rather in the multiples and submultiples of those units. Those who thus oppose the abandonment of our present system in favor of the metric system may fairly be asked, however, for constructive suggestions, especially if they admit the existence of crudities and imperfections in our present system. In fact they might well adopt the declaration of the British Weights and Measures Association, as to the objects which it seeks to promote, viz: "The Defense, Standardizing, and Simplifying of British (and American) Weights and Measures."

88 The Constitution gives to Congress the power "to fix the standard of weights and measures." But, says Mr. Adams, "It may be doubted whether under this grant of power is included an authority so totally to subvert the whole system of weights and measures, as it existed at the time of the adoption of the Constitution, as would be necessary for the introduction of a system similar to that of the French nation. To *fix* the standard appears to be an operation entirely distinct from changing the denominations and proportions already existing, and established by the laws, or immemorial usage."

89 The basic units of the British and American systems compare as follows:

Pound avoirdupois, 7000 grains; alike.
Pound troy and apothecary, 5760 grains; alike.
Linear inch, foot, yard and mile; alike.
Square inch, foot, yard and the acre; alike.
Cubic inch, foot, yard and the ton; alike.
Gallon, British 277.274; American, 231 cubic inches.
Bushel, British 2218.192: American, 2150.42 cubic inches.

90 The official standards of both nations are thoroughly established, and are in harmony. The reconstruction of our scales or tables, even though the basic units are left unchanged, would be a proper subject for governmental investigation and action, but in attempting such action, we should follow the example of France and of Germany, by referring the subject to a competent commission of technical experts, representative of all the sciences, arts, and industries, and should utilize the final findings of that commission as the foundation for legislative action by Congress. In thus organizing for the investigation of this most important subject, however, we

should seek not only to determine what shall be our permanent system, but, if the existing system is retained, to promote and maintain our present national *unity* as to weights and measures, and also, if possible, to bring about complete unity with Great Britain, whose weights and measures are already identical with ours save in respect to those of volume, the gallon, and the bushel. By international coöperation it should be possible to eliminate this element of difference, and to bring the weights and measures of the two great branches of the Anglo-Saxon race into perfect harmony; possibly also into some practical and helpful relation to at least some of those of the metric system.

91 The reader who has followed the argument set forth in these pages will perceive that it is intended to present and justify the plea in which it culminates, viz: that a Technical Commission should be created to which should be referred, for investigation and report, the whole subject of our weights and measures, including the possibility of improving our present system and also the expediency of substituting for it the metric system, the conclusions finally reached by this commission then to serve as a basis for legislation by Congress, and if necessary also by the several States. The writer has not attempted to conceal his present conviction that the disadvantages involved in abandoning our existing system of weights and measures for the metric system seem to far outweigh the advantages, nor his further conviction that our present system may be simplified and improved without disturbing the basic units on which it rests, but he recognizes with equal frankness the importance and vastness of the questions thus involved, the improbability that all of them can fully be appreciated by any individual, and the fact that a decision which shall be based on a clear understanding of all of the many sides of the question, which shall recognize and protect all of the many interests concerned, and which, being thus both sound and fair, shall command the approval and the permanent acceptance of the American people, can only be reached through the instrumentality of a commission composed of recognized experts in science, industry, agriculture, and commerce, to which should be accorded the time, the opportunity, and the means for pursuing its work in the most efficient manner and until the end in view has been attained. Therefore, when he appeared on behalf of the Merchants' Association of New York, as a witness before the House Committee on Coinage, Weights and Measures, on April 4 and 5, 1906, and made an oral argument against the then pending Littauer bill substantially on the lines of this paper, and when at its close he was requested, by a member of

that Committee, to draft and submit a bill which should give effect to his suggestions, he took pleasure in complying with that request, and subsequently, assisted by a friend versed in the law, submitted the draft of such a bill. That bill (H. R. 19,469) was introduced on May 18, 1906, by the Hon. Mial E. Lilley, and was referred to the House Committee on Coinage, Weights, and Measures. The text of the bill is given in an appendix to this paper.

92 The purpose of the argument herein presented is to call attention to the bill thus introduced, to insure a fair consideration of its terms, and to assist in an understanding of its purpose. The subject of our national weights and measures is one which concerns every citizen, and which has a direct and important relation to our national industry and national welfare. President Washington, in his first message to Congress, dated January 8, 1790, said, "Uniformity in the currency, weights and measures of the United States is a subject of great importance and will, I am persuaded, be duly attended to." His expectation was realized long ago as to our currency. Practically it has long been realized also as to our weights and measures, in which, as heretofore pointed out, we already enjoy absolute national uniformity. We are confronted, however, by the fact that a substantial number of our people honestly and sincerely believe that we should abandon our present system of weights and measures and should substitute in their place the metric system. These have urged, for many years and with great persistence, the change thus implied. Others, with equal sincerity and earnestness, oppose such change, although some at least of them believe that it may be possible, without changing our units of length and of weight and perhaps without changing even those of volume, greatly to improve our system of multiples and submultiples of these units, and at the same time possibly to bring about changes, either in our own system or in the British system, or both, which shall bring into complete and perfect harmony the weights and measures of both branches of the Anglo-Saxon race.

93 Surely, the trifling expense involved in the creation of the proposed commission, whether national or international, is abundantly justified by the promise it would hold forth of useful accomplishment in a wise and permanent solution of the problem of our national weights and measures. If so, it is to be hoped that all citizens to whom this plan appeals as the best mode of solving this important problem, will unite in approving and urging the creation of the proposed commission. If a commission is appointed there is good reason to believe that the British government, if invited thereto by the

President, will participate in the proposed work, either by creating a like commission or by appointing delegates to ours to make the latter international, as in the case of France in 1790, when five other nations were represented on the commission which finally reported in favor of the metric system. If the commission is appointed, and pending its final report, it may also be hoped that all further agitation of this subject, either in Congress or elsewhere, may be suspended. Let us have *light*, and then a *lasting peace*.

APPENDIX A BILL FOR A TECHNICAL COMMISSION

59th Congress, 1st Session. H. R. 19469. In the House of Representatives, May 18, 1906, Mr. Lilley, of Pennsylvania (by request), introduced the following bill, which was referred to the Committee on Coinage, Weights and Measures and ordered to be printed.

A BILL

Creating a commission to investigate the subject of weights and measures.

94 *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled*, That a commission is hereby created, to be called the Commission on Weights and Measures, which shall be composed, in the discretion of the President, of not less than nine nor more than fifteen commissioners, to be appointed by the President, by and with the advice and consent of the Senate, and to be selected from various professions and pursuits and in such manner that, so far as practicable, every important interest, particularly scientific, industrial, agricultural, commercial, mechanical, and maritime interests shall be represented thereon. Any commissioner may be removed by the President for inefficiency, neglect of duty, or malfeasance in office, and the President, by and with the advice and consent of the Senate, shall fill by appointment all vacancies which may occur in said commission.

95 SEC. 2. That it shall be the duty of the said commission to investigate and to report to the Congress upon the subject of measures of length, weight, and volume in use throughout the United States and in other countries, in order to enable the Congress to decide what action, if any, is feasible and expedient for the improvement of the system of weights and measures now in use in the United States, and to that end the investigations of the said commission shall include: First, the question of retaining or modifying any or all of the present standards of length, weight, and volume employed in the United States; second, in case present units are to be retained, the

question of improving and simplifying, especially for the purposes of computation, the subdivisions and multiples of such units; and third, in case any or all of such present units are to be discarded, the desirability and expediency of substituting therefor the so-called metric units and the system based thereon.

96 SEC. 3. That each commissioner so appointed shall receive a salary during his term of office of three thousand dollars per annum; that the office of the commission shall be located in the city of Washington, District of Columbia; that the commission shall give reasonable time for public hearings, if any shall be deemed necessary; that, if expedient, it may appoint a subcommission or subcommissions of its own members to make investigation in any part of the United States; that it shall have the authority to send for persons and papers and to administer oaths and affirmations. It shall be authorized to employ such assistants and clerks as it may reasonably require for the proper conduct of its work, and may fix the salaries to be paid to all persons employed by it, and that all necessary expenses, including the salaries of the commissioners, clerks, stenographers, messengers, rent for place of meeting, and printing and stationery, shall be paid from any money in the Treasury not otherwise appropriated, however, not to exceed one hundred thousand dollars per annum for expenditures under this section, to be paid upon vouchers to be approved by the chairman of the commission. That the commission is empowered to make all necessary, convenient, and proper rules and regulations of practice and procedure for the transaction of its business.

97 SEC. 4. That the said commissioners shall proceed with their work as rapidly as may be consistent with thoroughness and shall from time to time report the result of their labors and investigations to the Congress, and that when their work shall have been concluded the said commissioners shall embody the result thereof and their definite recommendations in a final report to the Congress; that their report shall be accompanied by notes which shall briefly and clearly state the reasons for the recommendations therein made and the legislation, if any, advocated by them.

98 SEC. 5. That immediately after the passage of this Act the President of the United States shall invite the Government of the United Kingdom of Great Britain and Ireland to participate in a conference for the improvement and unification of the standards of length, weight, and volume used by the United States and by the United Kingdom, such conference to be held at such place or places in Europe or in the United States as may mutually be agreed upon by the Executives of the two Governments, and that the President shall,

by and with the advice and consent of the Senate, appoint from the commission to be created under the provisions hereof, five commissioners to attend such joint conference on behalf of the United States. The commissioners so appointed members of such international conference shall receive a salary, additional to that provided under section three hereof, of two thousand dollars per annum and also their reasonable expenses as commissioners to such international conference, to be approved by the Secretary of State, said compensation and said expenses to be appropriated out of any money in the Treasury not otherwise appropriated.

APPENDIX B

99 Translation of an official letter from the Minister of Commerce, Industry and Labor to the Presidents of the Chambers of Commerce in the cities of France, illustrative of the persistence, even in that country one hundred and five years after its adoption of the metric system, of the older units of measurement. Furnished to the writer by Mr. Samuel S. Dale, and with his permission published herewith.

THE FRENCH REPUBLIC

PARIS, April 11, 1906.

The Minister of Commerce, Industry and Labor to
The President of the Chamber of Commerce at.....

100 My department at different times has been called upon to give to the Department of Weights and Measures instructions for accomplishing the total suppression of the measures and weights prohibited by the old law of July 4, 1837, by the seizure of the prohibited articles. The Department, in spite of all such efforts, has not succeeded in attaining the desired result. This situation appears to be due to the persistence with which certain trades continue to use the proscribed standards, their so doing leading to the use of the prohibited weights and measures.

101 I have learned that in certain industries the advertisements, prospectuses, catalogues, etc., used by the merchants, among themselves and also for sending to their customers, contain the illegal expressions. The merchants will invoke without doubt the necessity under which they find themselves not to change the existing order of affairs for fear that thereby they may lose orders for their goods. They thus continue to designate in lignes and inches all the articles they sell. It is true that in certain cases these measures are used rather to indicate sizes than for the purpose of invoicing merchandise.

Nevertheless the result is an objectionable usage which creates obstacles to the efforts made by my department to bring about the complete disappearance of weights and measures alien to the metric system, notably the division of the meter into inches and lignes.

102 I do not consider it worth while to enumerate here the industries and professions which have continued to employ the proscribed standards, but they are still numerous and most of them known to members of your organization. I do not think there is need to require from the agents of the Service a strict application of the provisions of Article 45 of the Ordinance of April 13, 1839, which requires them to report to the Recorder all violations of the law in regard to prohibited weights and measures which they may discover in advertisements and announcements. I recognize that if such a procedure were followed a considerable number of trades would be incommoded and much trouble be caused in the commercial operations of many manufacturers.

103 Under these conditions I have been led to make an investigation as to whether it is not possible to bring about a change in the present usage by some other method than that of repression, and therefore I addressed the Chambers of Commerce asking their members to use their influence both with commercial bodies and with merchants themselves to induce them to renounce practices which are contrary to the provisions of the law.

104 I am persuaded that the appeal thus made to them by the government will not find them indifferent, and that they will lend their assistance to bringing about the disappearance of the last vestige of the weights and measures in use before the creation of the metric system.

105 I shall be obliged to you for an acknowledgment of the receipt of this circular, of which I have sent a copy to the Inspectors of Weights and Measures, who being in daily contact with the manufacturers and merchants can supply you with valuable information regarding the industries in your vicinity in which the old standards are still in use.

The Minister of Commerce, Industry and Labor,

GASTON DOUMERGUE.

DISCUSSION

MR. H. H. SUPLEE Mr. Towne has presented the argument for a technical commission to investigate and report upon the subject of weights and measures so effectively that no further testimony is needed upon that point. Certainly anyone who was present at the recent hearings before the House Committee on Coinage, Weights, and Measures will agree that the subject should be placed in the hands of a more highly specialized body than was there possible.

2 It may be of interest, however, to place upon record, in the Transactions of the Society, the precise manner in which the metric system was actually adopted by the French Government, so that the members of the Society may have an opportunity of seeing just how that much discussed adoption was effected. I, therefore, give a complete translation of the law of July 4, 1837, referred to in the letter of the Minister of Commerce, in Appendix B of Mr. Towne's paper; this law still being in force, and being the statute which M. Doumergue states that he has found impracticable to enforce.

3 This translation is made from the text as given in the important work by M. G. Bigourdan, of the Paris Observatory, entitled "*Le Système Métrique des poids et Mesures. Son Établissement et sa Propagation Graduelle, avec l'Histoire des Opérations qui ont Servi a Déterminer le Mètre et le Kilogramme.*"

4 This work, which is the most complete and authoritative account in the French language of the origin and development of the metric system, gives in detail the discussions in the Chamber of Deputies and the House of Peers preceding the final passage of the law, and it should be consulted by anyone who desires the full particulars of the subject.

5 The law of the 18th Germinal in the Year III, of the French Republican Calendar (April 7, 1795) describes the metric system substantially as it exists today, provides for the establishment of standards, and forbids the manufacture of the old weights and measures. This law contained no compulsory enforcement clause.

6 The law of the 19th Frimaire of the Year VIII (December 10, 1799) defined the standard meter and kilogramme to be those deposited with the *Corps Législatif* by the Academy of Sciences, reaffirmed the remainder of the law of 18th Germinal, Year III, and ordered the striking of a medal to commemorate the event; but still failed to include any enforcement clause.

7 The Decree of February 12, 1812, issued by Napoleon, was intended to meet the objections to the metric system, and provided for the use of certain fractions of the metric units, to be known by the old names, the foot being one third of a meter, but divided into 12 inches; a pound equal to one half kilogramme, but divided into 16 ounces, etc. With these brief explanations, the law of 1837 is given.

8 Projet of the Commission of the Chamber of Peers of France, passed by both chambers of the French Government, becoming law on July 4, 1837.

Article 1 The decree of February 12, 1812, concerning weights and measures, is hereby repealed.

Article 2 Nevertheless, the use of instruments of weighing and measuring prepared for use in accordance with articles 2 and 3 of the above mentioned decree, will be permitted until January 1, 1840.

Article 3 From January 1, 1840, all weights and measures other than the weights and measures established by the laws of 18 Germinal of the Year III, and 19th Frimaire of the Year VIII, constituting the decimal metric system, shall be forbidden, under the penalties included by Article 479 of the Penal Code.

Article 4 Those who shall have in their possession any weights and measures other than the weights and measures referred to above, in their warehouses, shops, workshops, or commercial establishments, or in the public markets, fairs, or bazaars, shall be punished, together with those who use them, according to Article 479 of the Penal Code.

Article 5 From the above date all denominations of weights and measures other than those contained in the table annexed to the present law, and established by the law of the 18th Germinal of the Year III, are forbidden in public acts, as well as in posters and advertisements.

They are also forbidden in all acts made under private seal, and in all commercial records or private writings to be produced in court.

Any violation of this law by public officials shall render them liable to a fine of 20 francs, which may be recovered by compulsion, as a matter of record.

A fine of ten francs shall be imposed for other offenders, this to be collected for each act or signed writing; each commercial record to be liable for but a single fine for each contest in which it may be produced.

Article 6 It is forbidden for any judge or arbitrator to render judgment or decision in favor of any individual upon any act, record, or writing in which the denominations forbidden by the preceding

article appear, until the fines incurred in the terms of the said article shall have been paid.

Article 7 The inspectors of weights and measures shall ascertain any infractions provided by the laws and regulations concerning the metric system of weights and measures.

They shall proceed to seize the instruments for weighing and measuring of which the use is forbidden by the said laws and regulations.

Their reports shall be considered legal evidence unless proof to the contrary is presented.

The inspectors shall make oath before the court of the local magistrate.

Article 8 The manner in which the verification of the weights and measures shall be regulated by a Royal Ordinance.

* * *

9 Ever since 1840 the French Government has been endeavoring to enforce this law. With new industries, or in lines of manufacture or trade in which the work was not closely tied to the past, these efforts have been largely successful, but in the old established industries we see the difficulties by examining the letter of the Minister of Commerce, pleading with the Chambers of Commerce to come to his aid and try to induce the numerous industries which still adhere to the use of the old denominations to give up their illegal ways, and at the same time admitting his own unwillingness to disturb trade by enforcing the strict letter of the law.

10 I may add that Article 479 of the Penal Code, referred to above, is the provision of the Criminal Code against the possession or use of false weights or measures.

MR. FREDERICK A. HALSEY The only possible object of such a commission as that proposed by Mr. Towne is to introduce changes in our weights and measures. Clearly if the commission is to do nothing there is no occasion for its formation and to approve its organization is to acknowledge formally the possibility and tacitly the need of change.

2 Mr. Towne points out the unsatisfactory nature of the decimal basis of our system of notation, and I may add that a change in our notation is fraught with possibilities of improvement almost infinitely greater than could follow any conceivable change in weights and measures, but because of the difficulties involved in changing the existing notation he concludes that "it must be accepted as a finality."

3 With this I heartily concur, but just as he accepts our system of notation, so I accept our system of weights and measures. Like the decimal notation, it is not ideal—few human institutions are—but the difficulties of changing it are so vast, the certainty of failure is so obvious and the results would be so serious that I am absolutely opposed to any action which shall countenance it.

4 Mr. Towne's forceful argument against changing to the metric system has a far wider meaning than he gives it, for it is primarily an argument against not change to the metric system, but change to any new system whatever. Our wonderful uniformity, which as Mr. Towne points out is unique in the history of the world and not approached in any metric country, would be sacrificed by any change, and this uniformity is worth a thousandfold all the conceivable advantages that might follow any conceivable change.

5 The term "base unit" used by Mr. Towne, means nothing until it is defined, and he cannot define it in a way that will harmonize with his desire to have such units unchanged. The inch is the base unit of the machinist; the foot of the carpenter; the yard of the textile manufacturer and merchant; the grain of the prescription clerk; the ounce of the druggist's salesman; the pound of the butcher; the quart of the milk dealer; the gallon of the oil merchant and the bushel of the farmer. Which of these shall the commission decide to be the base units to remain unchanged while the others are changed?

6 The fundamentally greater difficulty of changing units of length as compared with changing those of weight and volume is well pointed out by Mr. Towne and has been pointed out by me elsewhere, but the difference is limited to the use of units in manufacturing industries. In the everyday commercial use of weights and measures there is no discoverable difference in the persistence of different classes of old units. The *libra* and *arroba* continue in use in Spanish speaking countries quite as persistently as the *pulgada* and *vara*, while the *livre* or half kilogram of France exists because it differs so little from the old Paris pound that in their everyday transactions the people did not know the difference.

7 Nothing is more certain than that the non-partisan unprejudiced commission which Mr. Towne has in mind is an impossibility. Every man whose opinion is worth anything has his opinion formed already, and, regardless of the method of forming it, such a commission would inevitably resolve itself into a bi-partisan or possibly a tri-partisan body. Agreement among these elements is impossible. The history of the discussion shows the entire inability of the scientific party to

appreciate the manufacturer's position. Until the recent appearance of Hallock and Wade's book the scientific party never so much as recognized that making things to measure differs in any manner or degree from measuring things as they exist and Hallock and Wade do not recognize it enough to hurt. Scientific men would enter such a commission with no object except to bring about the adoption of the metric system and the deference paid to scientific men today would introduce serious danger of their success. Were such a commission possible, the salary proposed is entirely inadequate to secure the services of competent men.

8 The final generalization from my examination of this subject is as follows:

No nation has ever made serious progress toward the adoption of the metric system in trade and commerce except by the force of compulsory law, and no nation has ever discarded its old units by force of compulsory or any other law.

9 There is no reason why progress toward the adoption of other new units should be easier or more rapid than toward the adoption of the metric units. Nothing is more certain than that the people of this country are satisfied with their present units and every reason advanced by Mr. Towne against forcing the people to use the metric units applies with equal strength against forcing them to use the new units which this commission must, if they do anything, devise. Universal compulsion in this matter is in this country unthinkable; success without such compulsion is impossible and failure means the destruction of our existing uniformity.

10 Our course in the future should be guided by the experience of the past, that is, by the experience of those countries that have attempted to change their weights and measures. The persistence of old units in so called metric countries and the resulting confusion is the answer to every attempt to introduce changes in weights and measures. In my paper "The Metric System," read before this society at the New York meeting of 1902, are a good many illustrations of this persistence of old units; in "The Metric Fallacy" are a good many more, and in the following letters which have been received since the publication of that book are still more. The circular letter of the French Minister of Commerce, Industry and Labor, given at the close of Mr. Towne's paper, is the final official confession of a Frenchman of the truth of all that has been claimed by Mr. Dale and myself regarding the continued use of old units in France. Alongside of it should be placed the following extract from the reply of the Chamber of Commerce of Amiens, France:

11 "The Chamber after having the circular read was unanimous in recognizing that it is illogical in a country like our own, where the metric system has been in force for so long, that prohibited standards of weights and measures should still be in use; but the Chamber considers that in view of the customs adopted by certain traders, it seems difficult, if not impossible, to arrive at a complete suppression of the actual conditions; that, moreover, such a radical and immediate suppression would cause profound disturbance in many industries, notably textile manufacturing."

12 "Such a radical and immediate suppression would cause profound disturbance in many industries" and this at the end of 112 years of effort and 70 years of compulsory law! What more is needed to complete the rout of the metric party?

13 The letters from which the following extracts have been made have all been received during the past two years. They relate chiefly to countries not covered by the disclosures of "The Metric Fallacy" and are offered here as supplementary to those disclosures. They all come from countries which appear as metric countries in every standard metric list.

FROM R. E. MANSFIELD, U. S. CONSUL, VALPARAISO, CHILE[1]

14 "I have to say that, notwithstanding that the metric system of weights and measures is in operation in Chile, the following old units of measurement are still used here:

Vara (Chilian yard) = 836 millimeters, used by all retail dealers in selling drygoods.

Yarda (English yard) = 914 millimeters, used by wholesale dealers of goods imported from Great Britain.

Libra (pound) = 0 .4601 kilogram, used by retail dealers in selling groceries.

Galon (wine-gallon) = 3.7852 liters, used by wholesale dealers of barreled liquors imported from Great Britain and the United States.

Fanega = 97 liters, used in the purchase and sale of potatoes and other country produce.

Arroba = 11.5 kilograms, used by retail dealers in selling groceries."

FROM CHARLES C. GREENE, U. S. CONSUL, ANTOFAGASTA, CHILE

15 "The 'Metric System' is the only legal system for all purposes in this district and for all Chile. In some places the old Spanish

[1]Chile first "adopted" the system in 1865.

measures are in restricted use, but in any question of law, all would be reduced to metrical equivalent. There is, however, one important exception; all contracts and quotations in Jackson Brothers' trade circular. The standards on the coast are in British sterling and weights. The Spanish quintal, that is for nitrate of soda, iodine, borax and etc., exported and certain staples imported, coal, coke, etc., but for Custom House entry these are all reduced to metrical equivalents."

FROM C. A. ORR, U. S. CONSUL, BARRANQUILLA, COLOMBIA[1]

16 "In reply to your letter of January 22, I have to state that it seems to be true in Colombia, also, that the metric system is not used by the people in trade and industry to the extent which one would infer. I am informed that the common people and retail dealers use very generally the English foot and inch; that the metric system is not used. In some of the small stores of this and I suppose other cities of Colombia, the Spanish 'vara' is used somewhat. Carpenters, masons and other artisans use the English system."

FROM ALBAN G. SNYDER OF THE U. S. CONSULATE GENERAL, BOGOTA, COLOMBIA

17 "The metric system is used here by all first-class people, and by the government as well in business of all kinds, but I am not aware that compulsory legislation exists as to its use, and if it does, it has not succeeded in preventing the use of old measures, for the merchants all use the yard as well as the meter, and retail merchants also use the Colombian measure, 'vara,' which is equal to 80 centimeters or 0.80 meters. This last named measure is used quite a great deal in ground measures as lots, farms, etc., for sale or purchase, in connection with the peasure or area called 'fanegada' which is generally four hundred fathoms square when applied to arable land, and 500 fathoms square applied to pasture land."

FROM E. H. DU BRUL OF CINCINNATI, WRITTEN AFTER AN EXTENDED TRIP THROUGH CUBA

18 "The Cuban Custom House gives out export figures on sugar and tobacco in kilos, but as a matter of fact, not a pound of sugar or tobacco is bought or sold in Cuba by the kilogram, but both are bought and sold by the Spanish arroba of 25 Spanish pounds.

[1] Colombia first "adopted" the system in 1857.

19 The farmer who sells his cane to the sugar mill has the cane weighed up in arrobas and gets paid for his sugar in arrobas. The price of sugar in the sugar market is quoted in 'reales per arroba.'

20 The reale above is a monetary denomination that does not actually exist, it being 12½ cents in Spanish gold. There is no coin of this denomination. Tobacco is quoted in the same manner.

21 Lumber is bought by the Cuban from the United States by the English foot and is sold by the Spanish foot, or Burgos vara of three feet.

22 The Cuban and Spanish carpenter, cabinet-maker, mason, blacksmith, and other ordinary building trades in Cuba, work by the Burgos vara.

3 For instance a certain box of standard size used in a certain industry measures 21 Burgos inches square. Article after article was measured up by me with a rule that had both the metric and Burgos measurements, and the articles in common use invariably corresponded to the exact measurements by the Burgos rule, but would have made many odd millimeters if measured by the meter side of that rule. It appears that the mechanic uses the Burgos side of his rule in making chairs, beds, wardrobes, doors, windows, tiles for flooring and wall tiles as well.

24 The stone mason would use the Burgos rule. A civil engineer in the Government service told me that in laying sidewalks in Havana, the official regulation is ten centimeters thickness, but as a matter of fact the cement workers in laying the sidewalk turn their rules around and use the English side of the rule, because it is so much easier for them to figure three inches of rough concrete depth in the sidewalk and one inch finish, the proportion being ¾ rough and ¼ finish, the ten centimeters approximating very closely to four inches English.

25 The ordinary artisan is of course familiar with the metric measurements but the point is that he does not use them. He says that the Spanish measurements are more familiar to him, and as a matter of fact, he is compelled to use them in working around old buildings.

26 Sugar land is rented out to the farmers by the plantation owner not by the hectarea but by the caballeria, another old Spanish land measure.

27 Piece goods in drygoods stores are invariably sold by the vara and not by the meter. The merchants are under the necessity to continually translate their invoices from France and Germany, after having imported the goods and declared them in the Custom House by

the meter, into the vara, in order to calculate their cost and selling price on the same basis of measurement.

28 In Cuba nearly every rule sold by the hardware stores to the mechanics has the English, Burgos and metric measurements.

29 The English measurement is used extensively by workmen in machine shops, etc., because so much machinery in the island has been built either in England or America, and naturally in replacing these parts, they do not take the trouble to first measure them off in millimeters, but just naturally measure them up under the system according to which the parts were built.

30 From my own observation, and I can testify to the fact, that Cuba, although the metric system is officially the system of the country does not transact the internal business of the country in metric weights or measures. The people use the measures they are accustomed to in spite of the official pronunciamento as to the use of the metric system, and the Spanish system has simply been overlaid with the metric, causing endless confusion and transposition back and forth from one system to the other.

31 Civil engineers, surveyors and others whose work lies largely, in calculations like the metric system on account of its decimal arrangement, but those whose duties lie in construction and in the actual handling of physical things all use the vara of 36 Spanish inches for measurement and the arroba for weights."

FROM R. E. HOLADAY, U. S. CONSUL, SANTIAGO DE CUBA

32 "In reply, I have to say that upon careful inquiry and investigation, I find that while the metric system has been officially adopted in this country, as the standard of weights and measures, it is by no means in general use by the common people in trade. There are some trades, professions, and mercantile establishments, however, that have adopted and use the system to some extent. Notably, physicians, druggists, and pharmacists, surveyors, carpenters and brick masons.

33 Physicians use it almost exclusively in writing prescriptions and, of course, pharmacists are obliged to use it in compounding medicines.

34 In the building trades the old English system is principally used in the actual every day work, but in obtaining permits for the construction of buildings all estimates, plans, etc., are required to be submitted in the metric system.

35 Surveyors use the metric system in both public and private

surveys, but in surveying land they set forth the dimensions in the escritura (deed) in both the metric and Spanish system.

36 Grocers and provision merchants use both the English and Spanish systems of weights and measures.

37 Dry goods merchants use both the Spanish varas (yard) and the English yard, depending very much upon which the customer demands. If nothing is said the varas is always used which is a fraction over three inches shorter than the English yard.

38 From the above it will be seen that there are three systems of weights and measures actually in use here, English, Spanish and Metric. The English system is the one most commonly used in the actual every day commercial transactions, but both of the others are used in certain kinds of transactions."

FROM MAX J. BAKER, U. S. CONSUL, CIENFUEGOS, CUBA

39 "The Metric system of weights and measures is established by law, and is adopted in all transactions at the Custom House, City Hall, and in the registry and records of property; in fact it is compulsory and adhered to in all official acts.

40 In the dispensing of all commodities, the common people are provided by retail dealers, in groceries all solid goods are sold by the ounce and pound, employing U. S. pound weights, as the scales are mostly of American manufacture, a few only being imported from Germany. Liquors are usually sold at wholesale in original packages, and at retail, by the bottle or fraction of a bottle, the poor people sometimes buying a few cents' worth.

41 The country's products such as cereals are sold by the pound or fraction thereof, except corn when sold in ears is sold by the fanega, which is 1,000 ears of corn. Vegetables are generally sold by the pound, the arroba or 25 pounds. Cabbages and bananas are sold in numbers from one up to one hundred or more.

42 Bakers employ dry wood which is sold by the cord. The cord measures 5.625 square Spanish yards. Coke is also used for cooking in ranges imported from the United States, Germany and France. It is sold at wholesale by the ton, and at retail by 100 pound bags. Laundries also use it. Wholesale drygoods merchants purchase their merchandise in Germany and France by the meter, in the United States by the yard, and they sell to the retail trade by the English yard, and the retailers sell to the consumer by the Spanish yard (called vara) and fraction thereof.

43 According to information obtained from master-builders contractors, and draughtsmen, they all agree that when they present

their plans and designs for official approval, they should be made in the metric system. Building materials, such as lime, are sold in bags measuring 36 inches long by 15 inches wide. Bricks are manufactured here, measuring 12 Spanish inches long, 6 Spanish inches wide, and 2½ Spanish inches thick, and are sold by the thousand.

44 In all masonry work such as building of walls, all measurements are generally done by the superficial Spanish yard. In foundations the work is done by cubic Spanish yards.

45 Importers of lumber from the United States sell all their lumber by English yard measurement. Domestic lumber is sold by Spanish feet.

46 Civil engineers and land surveyors employ the metric system throughout their measurements. Mechanics in general make use of English inches as their unit of measures."

FROM HERMAN R. DIETRICH, U. S. CONSUL GENERAL, GUAYAQUIL, ECUADOR[1]

47 "The above, as said, are the official measurements used in the Custom House, etc. The general public, however, use various other measures for their transactions and these are:

For measuring lengths of goods in stores, the 'vara' about 33 inches. Also the 'pie', a foot of 12 inches is used in stores.

For liquid measure they also use 'liter' and 'botella,' by 'botella,' meaning a regular wine bottle. Also use 'gallon' which holds here the equivalent of about five wine bottles.

For weights the 'libra' or pound is used, 100 libras making one 'quintal' and the quintal is equal to about 101¼ American pounds avoirdupois.

48 The quintal is divided into quarters, each quarter being called an 'arroba' of 25 libras. As the building material used here is principally wood, the measurements in building are very simple, being made by the American foot of 12 inches, because all the imported wood comes from there and is invoiced to the importer by that measurement."

FROM ROBERT GRIMSHAW, AN AMERICAN ENGINEER RESIDING FOR MANY YEARS IN GERMANY[2]

49 "Although an enthusiastic advocate of a decimal, as opposed to a duodecimal or an octonal, system of weights and measures, and of the meter as a standard, as against the yard, simply because it is so

[1]Ecuador first "adopted" the system in 1856.
[2]Germany first "adopted" the system in 1870.

generally adopted, and not for any reason of inherent superiority, I must in reply to a prominent manufacturer give the facts as regards the use of the foot and the inch, together with a number of other equally antiquated arbitrary measures of quantity—in the German, Russian and Austrian lumber trade.

50 The usages vary with the district, and those for the import and export trade are also different from those used universally in domestic business.

51 In the districts of Königsberg, Memel, and Tilsit, English measures are used for foreign business (which is about all that there is) in Danzig, English, Rhenish, and old French feet and inches, and the meter. For trade to England and Denmark, the freight from the latter port is figured in English 'loads' of 50 cubic feet each. Posen uses the metric system, also the Rhenish foot, 32.346 cubic feet going to a cubic meter. The same is true of Berlin. Breslau has the metric system, but if feet are used, they are Rhenish. Magdeburg gets much rafted lumber down the Elbe, from Bohemia, and this is often measured by the Saxon 'ell' of two Saxon feet. Rhenish feet and inches and meters are also here employed. The 'shock' is sometimes used; the conversion being in the ratio of 270 meters—860 Rhenish feet—886 English feet to one shock. In Wien (Vienna) only metric measures are known, except in connection with staves, which are measured by French inches, of which 36 equal 976 millimeters. In Thorn the old 'zopf' is still used for standing and rough timber. In Hamburg the metric is the leading standard, but it is to be expected that in a port having so much trade with foreign countries there will be the necessity of taking cognizance of foreign measures, be these ever so ridiculous in their relations with each other. For foreign shipments freight may be reckoned in 'English freight measure,' 'gross measure,' 'caliper,' 'Queen's caliper,' 'gross caliper freight measure, etc.,' as well as in cubic feet. In Bremen the sole measure given in the official regulations seems to be metric, but no doubt it is here as well as in all other shipping and receiving ports, necessary to be able to convert metric into other units, and vice versa. In Triest, there are used the meter and also the foot; staves are measured in width by inches and in thickness by lines. There are, unfortunately, two kinds of inches, arising from the previous political relations of the province—the Viennese of 26 millimeters and the Venetian of 30. Bromberg has the metric system alongside of the Rhenish; logs in the water are measured by the old Rhenish 'Kettenmass' or chain measure. In Riga, Russia, where of course the meter is also legal, planks are measured by the 'standard' of 165 English cubic feet.

The 'Hobelgesellschaft' or Union of planing mill proprietors, uses as legal measures the meter and its derivatives, but decrees that where feet are used the relations shall be as 328 to 100."

FROM D. E. McGINLEY, U. S. CONSUL, ATHENS, GREECE[1]

52 "During the last year a semi-official chart of the official weights and measurements of Greece was published, which gives the Greek measures and American equivalents. An examination of these tables shows that some confusion exists in these weights and measures, there being four 'piks,' two 'stremmas,' two 'kilons,' two 'dactylos,' and three cloth measures. The 'royal pik' is the length of the French meter, 39.37 inches; the 'mason's pik' is a little more than 29.52 inches; the 'endeje,' or small commercial pik, is slightly over 25.51 inches; and the 'bratzo,' or large commercial pik, is over 26.33 inches. The mason's pik is used in measuring mason work, and the last-named two piks for measuring cloth. The third cloth measure is the 'yard,' which lacks a fraction of an inch of the length of the American yard. It is used mostly in the Ionian Islands.

53 The stremma is a square measure, and the two stremmas in use are the 'royal' which equals a little more than 39.53 square rods and the 'old,' which equals a little more than 50.21 square rods. Why the old stremma is retained in use I have not learned. There are 4.047 royal stremmas in one American acre.

54 The two 'kilons' are measures of capacity, the 'royal' containing over 3.53 cubic feet and the 'old kilon' 1.171 cubic feet. Another measure of capacity is the 'hekatolitrom,' which is exactly the size of the royal kilon.

55 The trades use the metric system principally, but there are exceptions, as the use of the pik and yard by tailors in measuring cloth. Timber and boards are measured by metric, English and Venetian measures.

56 The unit of weight is the oka, which equals 2.82185 pounds. Up to the time the chart above mentioned was issued, the Greek oka was variously stated to be equal to 2.8518 pounds, 2.84 pounds, and 2.6998 pounds, but the official measures printed on this chart show that the oka is 2.82185 pounds in weight. I have been informed that in the Ionian Islands 2.6998 pounds is considered an oka.

57 For heavy weights the royal kilon, commonly called a 'kilo,' and equalling 75 okas, or 211.6987 pounds, and the 'tonos' (ton), equalling 2,204.6 pounds, are used. Wine, beer, liquors, oil, milk,

[1]Greece first "adopted" the system in 1836.

vinegar, syrups and other liquids are sold by the oka, on the mainland of Greece, but in the Ionian Islands the 'secchio,' 3 gallons, the 'pagliazza,' 1.99 gallons, and the 'barile,' 17.626 gallons, are said to be still in use."

FROM ALFRED A. WINSLOW, U. S. CONSUL GENERAL, GUATEMALA CITY, GUATEMALA[1]

58 "I have to say that the yard measure is more in use here than the metric system. The Spanish yard is generally used. As for weights, the pound is the most generally used."

FROM W. E. ALGER, U. S. CONSUL, PUERTO CORTES, HONDURAS

59 "Though some years ago Congress decreed that only the metric system should be used, it has never gone into effect, except in customs and there only weights are used, duties being based on kilos, while wharfage and other charges are on pounds. All units on lumber, etc., are same as in the United States. In the retail of drygoods, both yard and vara are used and understood by all."

FROM DEAN R. WOOD OF THE U. S. CONSULATE-GENERAL, CIEBA, HONDURAS

60 "The metric system has been officially adopted by this Government, and is used in all Government work. It is, however, never used by the people and merchants in trade.

The weights and measures used by the merchants here are the same as those generally used in the United States from whence most of the scales, etc. used here are imported. In selling groceries, etc., the same pounds and ounces are used as in the United States, and in selling liquids the same pints, quarts and gallons. In selling such articles as corn the 'arroba' is often used. The 'arroba' is equal to 24 pounds. In selling cloth the Spanish vara (33 inches) is sometimes used."

FROM JOHN H. RICHARDSON, U. S. CONSUL, UTILLA, HONDURAS

61 Upon the Bay Islands the English standard of weights and measures is used. I know of no use of the metric system."

FROM ALEXANDER HIMGARTNER, U. S. CONSUL, CATANIA, ITALY[2]

62 "I give below some of the weights and measurements in use. As an illustration of the annoyances of the old systems (and it seems

[1]Guatemala first "adopted" the system in 1895

[2]Italy first "adopted" the system in 1845

impossible to eradicate them) the 'salma,' a wine measure, differs in adjoining towns, and what is more remarkable, in some parts of the Island, values are estimated in the old money unit of 'onza,' divided into 30 tari of 20 grams each, the onza equaling lire 12.75.

In the small trades the liter is universally employed.

WEIGHTS AND MEASURES IN USE

Rotolo (divided into 32 onza) = 793 grams
Libra = 317.368 grams
Canna (8 palmi), 1 palmo = 0.258098 meter
Cantara = 79.342 kilos
Tumolo (grain) = 17.193
Miglia = 1 kilometer, 486 meters, 64.34 centimeters
Salma = 2 hectoliters and 75.89 liters

FROM BEN JOHNSON, SUPERINTENDENT OF MACHINERY, MEXICAN CENTRAL RAILWAY[1]

63 "The happy condition of things in Mexico as to the metric system (portrayed by F. Susteric in the 'Engineering and Mining Journal' of April 27, p. 808) is so far different from that prevailing in the shops under my direction, and from anything that has come under my notice in others, during four years' service in Mexico, that I have been prompted to make inquiries as to the practice of the principal railroads and commercial plants of Mexico.

64 I wrote to the heads of the mechanical departments of five of the most important railroads of the republic, all of whom answered to the effect that as far as all shop measurements of gages, drawings of locomotives and cars, and of other apparatus made in shops, is concerned, the metric system is unknown and English measures are used entirely.

65 The manager of one of the most important commercial shops in the republic (who has been for 25 years, and is still doing important engineering work) assured me that the same condition exists in his shop. One of the most prominent manufacturing firms, owned and conducted by Mexicans, writes me: 'In regard to the metric system, will say, that in our shops we use both the metric and English systems. In fact, all of our calculations of strain of materials, and floor plans, are based on the metric system, while the sizes and dimensions of material, lathe work, etc., are based on the English method.'

[1]Mexico first "adopted" the system in 1862.

66 All reports and plans for submisson to the government are, of course, made as requested by law, in the metric system.

67 The 'illiterate Indians' may have adopted the metric system; but if there is any important machine shop that has done so for its own use in construction work, I have yet to learn of it.

68 I think that the fullest investigation will sustain the opinion I have just expressed and will be glad to submit the original letters, referred to above, to your inspection if of interest."

FROM CHARLES E. WESCHE, VICE-CONSUL, CIUDAD JUAREZ, MEXICO

69 Here at C. Juarez and other border towns the carpenter and builder carries and uses his 'two foot' rule, and all building material is bought and sold by the same measurement which is prevailing in the United States. The drygoods merchant measures his wares by the 'vara' (33 inches) when dealing with the natives, while in his traffic with Americans he buys and sells by the yard. In the fuel trade fire-wood is sold by the cord and coal by the ton. Liquor dealers sell by pints, quarts and gallons."

FROM CHESTER DONALDSON, U. S. CONSUL, MANAGUA, NICARAGUA

70 "I have the honor to enclose your list marked as desired, and report that although the metric system has been officially adopted by the Government of Nicaragua, it is not used in practice, either by merchants, farmers or mechanics.

Cloth is sold by the Spanish vara = 33 English inches.

Railroads are measured by the English mile.

Sugar, etc., by the pound avoirdupois 16 ounces = 1 pound.

Surveyors use, as a rule, Spanish measurement.

FROM H. A. GUDGER, U. S. CONSUL-GENERAL, PANAMA[1]

71 "The official standard of this Republic is the Metric Sytem of weights and measures. In everything of an official character this system must be used. In buildings as well as the sale of land the same system is used. In buying and selling the merchants do not use this system. In other words, while it is the officially recognized system, yet it is not in common use."

FROM REV. GEORGE D. RICE, U S. ARMY CHAPLAIN, PHILIPPINE ISLANDS[2]

72 The information regarding the Philippine Islands is obtained from a letter from Rev. George D. Rice, a United States army chap-

[1] Panama as part of Colombia "adopted" the system in 1857.

[2] The Philippines Islands first "adopted" the system in 1850.

lain stationed in the Philippines. This letter will be found in full in a hearing before the Committee on Ways and Means of the 58th Congress, relative to the Tariff Laws of the Philippine Archipelago, dated Ferbuary 10, 1905. From it the following extracts are made

73 "The mixture of the Spanish vara used here with the English, Filipino, and other systems of measurement is quite bewildering. The meter of the metric system is also used with the local standards. There are many Chinese, Hindoo, and some German merchants, and they have introduced various systems of measures. The common people, when left to themselves, use the straight Spanish tables of measurement, as the Spanish have published these for them. The vara is understood by all. The metric system is used in the railway service, the custom house, and other Government offices. The railway, however, is controlled by the Spaniards. The storekeepers, carpenters, masons, artisans, and others generally use the Spanish measurements. I have always heard the boss carpenters and others in charge of work give directions regarding dimensions to the workmen in Spanish terms and according to the Spanish tables. Occasionally a school-trained worker speaks of inches, feet, yards, and etc., but not often. The same condition is found in land measurements by the farmers. A friend explains to me how many square yards he has purchased from a native land owner, and then in addressing the natives uses the native terms entirely. Farm produce is measured out in square wood boxes marked with Spanish measures.

74 The Spanish and Filipinos have queer methods for measuring material in bulk. The Chinese follow suit. Instead of metal quart utensils one sees square wooden boxes numbered as shown in figure 6. Letters of figures corresponding to the Spanish or Filipino standards are stamped or burned on them to indicate how much rice, grain, flour or other dry stuffs they will hold. The boxes are often soiled and cracked, but all are tested as to the contents and passed by the inspector so that correct measurement is assured. Sometimes the entire outfit is made up of tubes of bamboo, all properly stamped with burnt letters and certified to by the inspector of weights and measures of the Archipelago. No undersized utensils are permitted. If any are found they are seized and the owners fined."

FROM W. F. DOWNS, A MINING ENGINEER RESIDING IN JERSEY CITY, N. J.

75 "I have just returned from a stay of ten months in Porto Rico. While there I had frequent occasion for annoyance over the confusion of weights and measures in vogue.

76 Distances on the government road are stated in kilometers and official surveys are given usually in meters, etc., but the Porto Rican land owner gages his land by the old Spanish acre or queida and sets the price accordingly.

77 In the stores goods are sold by the pound and you must watch to see whether you get a Spanish or an English pound. In the towns the price will sometimes be given by the kilo though cattle are bought and sold by the arroba. Drygoods are measured by the vara though you can also buy by the yard and meter. In the coffee and sugar districts many use the quintal as the unit of weight of goods in bulk.

78 As for tools I saw very few, but such as I noted in the hands of native mechanics, such as squares, rules, etc., were all divided into Spanish inches."

FROM C. L. MAXWELL, U. S. CONSUL-GENERAL, SANTO DOMINGO

79 "In replying to yours of January 21, 1904, I have to state that the American measures and weights are in general use here. In drygoods they use the Spanish vara for the yard, equal to 34 inches American."

FROM A. W. LITHGOW, ACTING U. S. VICE-CONSUL, PUERTO PLATA, SANTO DOMINGO

80 "The Dominican Government collects its duties, based on the English yard and pound. Drygoods are sold at wholesale by the English yard, but the retailer sells the same by the Spanish 'vara' which has 33 English inches. Provisions are bought and sold by the English pound. Produce of the country is bought by the kilo, calculating one kilo as two pounds. All the lumber used here is imported from the United States, so the English measures are used in the building trades, with very few exceptions, use the metric system."

FROM JOS. BOWRON, U. S. CONSUL, CARTHAGENA, SPAIN[1]

81 "The great bulk of retail transactions (probably 95 per cent) are done in the old weights and measures. Drygoods are sold by the yard or palmo ($\frac{1}{4}$ yard); wine, grapes, rice, etc., by the arroba (=11.5 kilos); grain by the fanega, a measure (wheat runs 40 to 42 kilos per fanega). Many storekeepers quote 'per kilo,' as being bigger and more attractive; but knowing nothing about grams, they divide up the kilo by fractions of pounds.

[1] Spain first 'adopted" the system in 1849.

82 I know that lumber is generally sold by feet and inches. In foundries and machine shops (few in number and unimportant), I understand that the metric system is used as a matter of convenience. Architects, bricklayers, etc., use the metric system in the larger towns; but in the smaller places the measurements are made in feet and inches.

83 Land is described, in official documents, in metric terms, with the equivalents in the old fanegas, tabullas, and celemines. Fuel is sold by Castilian quintals, of 46 kilos each. Flour for domestic use is usually sold per cuarteron = 6¼ pounds."

FROM J. L. BYRNE, U. S. VICE AND DEPUTY CONSUL, VALENCIA, SPAIN

84 "The traditional systems of weights and measures still obtaining in this district in nearly all local or home commercial transactions on small scale are the most confusing and complicated imaginable."

FROM D. R. BIRCH, U. S. CONSUL, MALAGA, SPAIN

85 "I consider it best to preface the following by the statement that, generally speaking, the matter is largely a question of education. The principal stores in the center of this city adhere to the metric system almost without variation, the drygoods stores selling by the meter and the grocery places by the kilo. But even in these stores a person desiring purchases by the pound or yard, as the case may be, could be accommodated.

86 On the outskirts of the city proper or in the nearby villages, the metric system is but little used, its place being taken solely by the yard and pound, respectively. The Spanish yard (vara) is 0.836 meters and the Spanish pound (libra) equals 460 grams, but is currently rated as a half-kilo."

FROM LOUIS GOLDSCHMIDT, U. S. CONSUL, LA GUAIRA, VENEZUELA[1]

87 "The metric system is very little used in Venezuela, except by the Government when calculating the duties upon imports or exports to and from this country. All duties paid are according to the weight of the article imported, and the weight must be stated in kilograms, and the duties are usualy a certain amount per kilogram. This is about the only application of the metric system in practical use. In ordinary trade the old system is still in vogue,

[1] Venezuela first "adopted" the system in 1857.

and although the imports of merchandise are frequently expressed metrically, all local trade is according to the old Spanish systems of pounds, or varas (yards), etc. The weights and measures of Venezuela are as follows:

Arroba (dry)	25 .4024 pounds
Arroba (liquid)	4 .263 gallons
Fanega (dry)	1 .599 bushels
Pound	1 .0161 pounds
Vara	33 .384 inches

Quintal equals 100 Venezuelan pounds.

88 Although most goods which are imported, generally are put up according to the system of the country of their origin, they are sold (even by the first importer) according to the usage of this country. Drygoods, which may be put up in meters or yards, are never sold in that way, but are figured over into varas, and the bills are made out accordingly. And so with other merchandise, excepting, possibly certain building material or timbers, which are usually invoiced according to the measurement of the country of their origin."

* * *

89 When opening their campaign before the House Committee on Coinage, Weights and Measures in 1901, the metric advocates based their case on the following assertions:

90 *a* The metric system is in universal use in all civilized countries except the British Empire and the United States.

91 The appendix to the report of the Committee of the 57th Congress contains a list of forty-three countries which are there stated to have adopted the metric system and this list has been republished far and wide as representing facts. In "The Evolution of Weights and Measures and the Metric System" by Hallock and Wade, is a table showing "the time at which metric measures were first adopted; when made compulsory, and, so far as can be ascertained and briefly stated, the extent to which they have replaced other and older measures."

92 From this table *twelve* of the countries which appear in the standard list are bodily omitted, in eight others the use of the system is admitted to be negligible and of four others the column giving the extent of the use of the system is blank, while of other countries the statements made are erroneous. $12+8+4=24$ which is more than half of 43.

93 *b* The adoption of the system is a necessity for the promotion of export trade. In reply it has been shown by the overwhelm-

ing testimony of exporters of machinery (in which Mr. Towne concurs above) that the call for the system in foreign trade in negligible.

94 *c* The adoption of the system would simplify our weights and measures. In reply it has been shown that the only effect of its adoption would be to superimpose a new set of units on the old ones, introducing far worse ratios than those that now obtain and thus complicate our system.

95 *d* The adoption of the system would lead to a saving of from two-thirds of a year to a year (sometimes stated as from two-thirds of a year to two years) in the school life of every chlid. In reply it has been shown that the entire time devoted to denominate numbers and weights and measures in the public schools of New York City aggregates less than six weeks, which the addition of a new system to the old one would increase and not diminish.

96 *e* The adoption of this system would introduce uniformity in our weights and measures and in reply it has been shown that we have now a degree of uniformity that is unapproached in any metric country and that this uniformity would be destroyed by the adoption of this system.

97 *f* The adoption of the system is an easy matter, the length of the transition period being seriously estimated by a dozen prometric witnesses before the Committee to lie between two and five years. In reply it has been shown that, in spite of the most drastic compulsory laws, the transition period is not yet over in any metric country, France included, and that in countries having laws similar to the one proposed here, there has been little and in some cases practically no progress toward its adoption in trade and commerce.

Rear Admiral Geo. W. Melville I have read with much care the admirable paper by Mr. Towne, and I want to say that, in the main, I agree with almost every word he says, but unfortunately I dissent from his conclusion that it is desirable to appoint a commission to consider this matter of weights and measures.

2 I am quite familiar with the efforts which have been made by various parties to force a bill through Congress, making the use of the metric system compulsory, and indeed have appeared before the House Committee on Coinage, Weights, and Measures and have also written them on the subject. It seems to me that Mr. Towne, in his desire to be absolutely fair to everybody, has hit upon this scheme of a commission, which at first glance seems an admirable method for arriving at correct views on the subject.

3 I am rather inclined to think that before the hearings on the

metric system I should have been quite ready to approve the idea of a commission to consider this subject, but the testimony which was given before the commission, and the attitude of mind which it showed as existing on the part of many men classed as scientists, makes me doubt very gravely whether the scheme for a commission would work out well.

4 It used to be one of the boasts of men who call themselves scientists that they of all men were absolutely fair in their investigation of a subject, that their great motto was truth, and that their whole effort was to ascertain and propagate the truth irrespective of personal or other considerations. The showing which the scientists made in the discussion of the metric system is certainly calculated to make the judicious grieve and to prove most conclusively that there are scientific bigots as well as theological ones.

5 To any unprejudiced person the published testimony must have shown with unmistakable clearness that the scientific men were not actuated by a desire to ascertain the truth, for the reason that after incontestable facts had been presented by competent experts as to the enormous cost and inconvenience of making the change they continued merrily to assert that the change would excuse a little inconvenience and so small a cost that both could be waived aside.

6 Scientific truths are not limited to more or less close guesses at distances of remote heavenly bodies, but include data of a financial and economic character when based on careful investigation and deduction from a sufficient number of reliable examples. Mr. Towne's paper is so calm and judicial in tone and states so well the real merits of the whole question of weights and measures that any further discussion of that side of the case seems unnecessary. I have said what has gone before to show my fear that if a commission were organised, some of the members would certainly be people who came with anything but open minds and who had proved conclusively that they are not prepared to discuss the matter in a really scientific spirit. It would seem to me, therefore, that however the commission is chosen, we would be almost sure to get a divided report and we would be just where we are now.

7 Further than this, it seems to me that Mr. Towne's own paper shows in an admirable way that there is no necessity for an elaborate investigation as to the desirability of a change. In the case of weights and measures, as of so many other things, the Anglo Saxon race has shown itself capable of handling the problem intelligently. The advocates of the metric system have made a great parade of the alleged enormous number of units to be remembered in English sys-

tems of measure, but Mr. Towne has shown in paragraph 89 that as a matter of fact, although the tables in the text books give a large number of units, the actual ones which are used are very few in number and are all of great convenience.

8 It seems to me that if we who believe the existing systems of weights and measures to be satisfactory, agitate for a commission to consider the subject, we are going even further than the case of a man who proposes to submit to arbitration the question of whether he has not an equal right to the watch which you have bought and carry. We think that absurd, but to ask for this commission is almost to hunt for a man to agree to arbitrate whether our watch does not belong to him.

9 Our experience in the United States has shown that in the long run we get substantially what we find to be best. We all know how the provision of the Constitution relating to the choice of the President by electors has been practically nullified so that the President is really elected directly by the people. We still go through the form of choosing electors but they are bound to vote for the candidate of the party with which they are connected. Different lines of work ultimately come to use the unit of weight or measure which is most convenient for them, and they do not wait for government authority or encouragement to do so. We have found by experience that the units of length, which on the whole are of most use, are the mile, the yard, the foot and the inch, as stated by Mr. Towne. The other units in the tables have practically dropped out. In the same way in the United States, our units for weights in general are only the pound and the ton.

10 Our own Society has set a splendid example in its consistent endeavor to secure uniformity and standardization where such were desirable and beneficial, and we have always found that where a real benefit could be shown to result, manufacturers were willing to incur considerable expense. My feeling is, and has been right along, with respect to the metric system, that if it became desirable to adopt it our people would do so under the permission already granted by law and would not need to be driven into it by compulsion.

11 Is it not worth remembering also that, while the Committee on Coinage, Weights and Measures, consisting as it does almost entirely of lawyers, is not a body of experts competent of themselves to pass on such a highly technical subject as this, nevertheless the scheme in a general way is somewhat like that of the jury system. There, if technical questions are involved, experts are called to testify and the jury decides after listening to their evidence. The Committee has

considered this subject now for a long series of years and, although at one time when the opponents of the compulsory use of the metric system had not had an adequate opportunity to present their side of the case, the Committee did report recommending such adoption, they have recently, after about four years of careful hearings of both sides, reported against it. Whatever the report of the commission, I do not believe it would settle matters at all. If it were so organized as to have a majority of scientific bigots we might anticipate a report recommending the adoption of the metric system. This would not convince the manufacturers and they would oppose any bill for such compulsory adoption just as strongly as they have already done.

12 On the other hand if there were a majority of manufacturers on the commission they would almost certainly report against any compulsory change in existing weights and measures. This would not satisfy the scientists, who would continue their propaganda with the same fanatical zeal which has characterized them hitherto.

13 While not agreeing with Mr. Towne that a commission is desirable, I wish again to express my high appreciation of his paper which I consider a very complete and judicial presentation of the case, which sets forth the whole matter in very clear shape, and which is especially to be commended for its fairness.

MR. JAMES CHRISTIE The creation of a technical commission as proposed by Mr. Towne, and as embodied in the Lilley bill, cannot fail to meet with the approval of the greater number of those who are interested in the subject of national standards.

2 Most of the proposed legislation on the subject has been wanting a stable foundation, and an intelligent comprehensive report by a commission that would duly consider all the phases of the question would tend to give a rational basis to future legislation.

3 It will not do for the few radicals of either side to attempt to decide the subject in an *ex parte* manner, as we can now see that the question will be periodically agitated. The extended adoption of metric measures in applied science, and its extension thence to the closely allied arts, is gradually bringing the subject closer to the thoughts and observation of the masses of the community.

4 As a single illustration, take the chemical industries. The adoption of metric measures in chemical science is resulting in its extension to the allied industries, and as the art of chemistry is constantly obtaining wider application, it would appear probable that there will be a gradual increase or spread of the metric system to industries associated with chemical science.

5 Our existing system of weights and measures is in a transitional stage, and the final result will be either that one method will be adopted to the exclusion of the other, or some compromise will be suggested that will command international support, or else we will have in existence two concurrent systems of weights and measures, which unfortunately bear no satisfactory relation to each other.

6 The respective merits and demerits of both systems under review, has been so amply expressed elsewhere, that repetition is needless. I might, however, state that the passage of years impresses on the writer that the clear mental image of the relation between large and small quantities when expressed in the decimal system is so manifest and desirable, and the absence of a similar mental conception in our system forms a sharp contrast in merit, from this point of view alone.

7 International uniformity is very desirable as a means of facilitating interchange of products. Leveling processes now in active operation will tend to obliterate the causes, which in the past have offered effective resistance to free exchanges, and it is good business policy to remove all restraint possible when other interests are not sacrificed.

8 Mr. Towne has stated his views very lucidly, and they form an interesting addition to the anti-metric argument.

Mr. William Kent Mr. Towne's valuable paper is a very important addition to the literature in antagonism to the adoption of the metric system by the United States. I do not see how any unprejudiced person (if any such person exists as far as this question is concerned) can read this paper without being convinced that the adoption of the metric system in this country to the exclusion of the English system is not only undesirable but also impracticable and impossible.

2 I am not sure that I favor at this time the appointment by the Government of a technical commission on the subject, but I certainly should favor the appointment of such commission rather than the passage of any other legislation whatever in regard to the system. It might be well to hold Mr. Towne's proposed bill until the next pro-metric bill is introduced in Congress and then have his bill for a technical commission introduced as a substitute. Let the two bills, for the metric system and for a technical commission, both be referred at the same time to the Committee on Coinage, Weights, and Measures and let that Committee report on each and on whether one of the two bills should be passed by Congress.

3 Mr. Towne makes some suggestions in regard to improving the English system and therefore this subject is open for discussion in connection with this paper. In regard to the "needless confusion" in the English system (paragraph 17), the confusion is not so bad as the metric advocates try to make it out. The pound troy and the apothecaries' pound are never used in commerce. The troy ounce is the unit for weighing gold and silver. Apothecaries' weight does not exist outside the prescription department of drug stores. On their sales counters the drug stores use the avoirdupois system and there is no such thing as a pound weight in the apothecaries' system to be found in any drug store.

4 The grain is rarely used in practice and it would be a good thing to discontinue its use entirely and substitute another weight, the 10,000th part of a pound = 0.7 of a grain. I have found it necessary in some work involving fine weighing to use the metric system simply because it was a decimal system and then convert the results back into avoirdupois weight, just because I did not have a set of avoirdupois weights divided decimally. An ideal system would be the avoirdupois pound with binary subdivisions down to one-eighth of an ounce and also decimally into hundredths, thousandths and ten-thousandths of a pound.

5 In regard to measures of volume (paragraph 18) it would be well to abandon all our gallons and use a new gallon of 216 cubic inches, which is six inches cubed, or $\frac{1}{8}$ of a cubic foot. The pint would then be three inches cubed, or 27 cubic inches, or $\frac{1}{64}$ of a cubic foot. The bushel might also be abandoned and the cubic foot used instead, or if it should be considered that the word "bushel" should be retained, it might be defined as $1\frac{1}{4}$ cubic feet or 2,160 cubic inches, or ten new gallons. This would only be 9.58 cubic inches more than our present American bushel and 58.19 cubic inches less than the British bushel.

6 In regard to measures of length, the furlong, rod, and rood are already practically obsolete. They are not needed in any industry whatever. The mile, foot, and inch are practically all we need, the yard being scarcely ever used by engineers except in cubic measure, but it will undoubtedly be retained for measuring textiles and no good purpose would be served by trying to get rid of it.

7 I do not wish to be understood as being in favor of the appointment of a commission to study the metric system at this time; in fact, I am opposed to any more legislation or agitation of the subject, but if there is bound to be an agitation brought about by the pro-metric advocates, then as the least of two evils I would rather see

Congress appoint a committee to investigate the metric system than to pass any other bill whatever in relation to it.

MR. J. SELLERS BANCROFT I have read Mr. Towne's able and very important paper with a great deal of interest.

2 The difficulty in the whole question of the introduction of the Metric system of measurements appears to me to be due to a lack of familiarity with manufacturing conditions, and the want of knowledge as to the investment in organization, drawings, tools, and gages required for the construction of machinery in duplicate.

3 I have been familiar with the Metric system since early in the 60's, a department in the works of William Sellers & Company (with which concern I was associated for more than forty years), having been operated entirely on the Metric system of measurement. The drawings for the original Giffard injectors having all been made on that system it was thought to be an excellent opportunity, as the manufacture was entirely new, to organize the department with the millimeter as the unit of measurement, and to this day I think of injectors, their dimensions, and proportions, in millimeters, but, after my long experience with this system, I am still of the opinion that the inch is a far better unit of measurement, and that for the great manufacturing world there is absolutely nothing to be gained by the transfer from our present system to the Metric system. On the contrary, the expense involved, and the confusion and difficulty of working under two standards for generations would be enormous.

4 To ensure a full consideration of this subject, the dissemination of information as to what the real facts are and what is involved in a change of the unit of measurement of length, I heartily approve of Mr. Towne's suggestion for the appointment of a technical commission for a thorough investigation of the question of standards.

MR. OBERLIN SMITH The very interesting and logical paper by Mr. Towne regarding the advantage of the use of the so called Metric system in this country so thoroughly covers the ground that it is hardly worth while for one who agrees with him to treat the matter at any considerable length.

2 Mr. Towne and many other engineers, including the writer, have argued the question in Washington before Congressional committees and have expressed their views freely in the field of magazine literature, etc. Few of us oppose the Metric system in itself, for it certainly is far more systematic and logical than the mongrel non-

system used here and in England. For purposes of calculation, the shifting of a decimal point to the right or left and so rapidly performing multiplication and division, respectively, unquestionably decides its superiority. This advantage is due to its being a *decimal* system, while the various other advantages are attained by the systematic relations of its different units to each other.

3 In performing the act of measuring neither the "Anglo-American," nor the Metric system has any special advantage because such special tools as scale weights, measuring cups, and graduated rules adapted to either system are cheaply obtainable. Naturally the recording of measurements in the decimal system has the advantage, as the fractions are all so much more simply expressed. Were we starting afresh, with new standards established in the dimensions of land and lumber and bar metals and shafting, also in innumerable accurate tools, such as gages, drills, reamers, taps, dies etc., then it is probable that the advantages of the Metric system would tip the balance, so that it would be wise to adopt it universally, both nationally and internationally. As, however, both Great Britain and America, with their colonies, have had the Anglo-American system in use for several centuries, and as enormous quantities of articles standardized under this system are in existence and will remain in existence for a long while to come, especially in the case of land measure, the difficulties of making a change are so tremendous, both as concerns time and money, that any change, even if decidedly for the better, must be very carefully considered. Nor should any such reform be made except upon a comprehensive scale, by the whole civilized world. It should be of such a permanent character that the subject need not again be agitated by any race of beings whose thoughts and habits are akin to ours.

4 To an engineer acquainted with the enormous complexity of our system of tools for industrial production, the idea of changing standards is something appalling in its magnitude, the expense of which, in this country alone, would not be measured in millions of dollars merely, but in billions. Should we make this change to the Metric system we would still have a very imperfect system of measurement, simply because it would be a decimal system. This seems beautiful to calculators, merely because we multiply and divide by sliding our digits sidewise in relation to unity. Many people have an idea that this beautiful simplicity of calculation arises from some mysterious and sacred quality in the number ten itself. They fail to realize that exactly the same convenience could be obtained were our radix 9 or 11 or any other number of reasonable size. The num-

bers above mentioned would not be quite as convenient as ten for the practical work of dividing tools or merchandise, because they could not, like it, be parted in the middle, so to speak. Ten, however, can thus be divided but once, and after that the natural, beautiful, and useful principle of *binary division* cannot be carried any further without an annoying series of fractions.

5 Without here specifying details, a little study will show that the binary principle is necessary in almost all kinds of work, from the division of a bushel of walnuts down into pecks and quarts to the graduations on a machinist's scale and to the folding and refolding of a sheet of paper. The only logical numbers for the radix of our numeration are eight and sixteen. These are advocated by many eminent mathematicians. The former is, in the writer's opinion, too small, as more figures would be required than now, upon an average, to express a given number. Sixteen seems to be the ideal number for a base or radix, as being not too large for one to remember easily the six new digits necessary and the new multiplication table which would be required. It is, moreover, much better than ten, aside from its binary feature, as requiring much less paper, ink, and writing in recording numbers. Thus, numbers as high as 255 would be expressed with two digits, and as high as 4095 with three digits.

6 There is no question in the writer's mind but that the whole civilized world will adopt this base, in spite of the enormous difficulties of the change, within a reasonable number of centuries. The time may be shorter than we think, because the reign of common sense in all things seems to be making for the simplification of work in all the walks of life; and this progress seems to be going on in a geometrical ratio.

7 In view of this possible and splendid change in the not too far off future, it would seem well to wait for it before trying to establish an absolutely universal system of weights and measures. Both great reforms could then be made at once (and might not even our villainous English spelling be reformed at the same time), and the world would settle down to a permanent system which would save an enormous amount of worry and work in dealing with figures and with material things.

8 Whether or not this is only an optimistic dream, let us for the present hold on to our good English inch, not because it is better in itself than any other analogous measure but because it is so well intrenched as to be almost indestructible. Should our base happily be changed to 16, we have already multitudes of standards based on 16ths, 32ds, 64ths and 128ths of the inch. To carry the binary

division still further down we would soon reach 1/4096″, which would be expressed in three figures exactly as 0.001″ is now. So fine a measurement would be about right for most of our mechanical work where the present 0.001″, commonly marked on our micrometers, is decidedly too large. Should the inch unit be retained indefinitely, as a world's measurement, the enormous volume of industries basing their standards upon it would not be destroyed. The longer measurements, as yards, rods, miles, and all the rest of the hodge-podge could easily have substitutes, with values which were perfect multiples of 16. For these larger measurements but few expensive tools have been made.

9 Should the greater change in question ever be brought about, it would probably be through the medium of some great international commission of mathematicians and engineers, working under the auspices of all the civilized governments of the world for many years. It could be adopted gradually by becoming part of the curriculum of every school, as children could learn it more easily than a new language.

10 As practical Americans and Englishmen, the only thing which it would seem best for us to do now would be to retain the inch and somewhat simplify the other lineal units, keeping in mind as an ideal for the future the beautiful number 16, which can be halved down to unity; which is a perfect square, a perfect 4th power, four times a perfect square and twice a perfect cube. Surface measure would of course be much as at present, with perhaps some simplification. Measures of weight and volume can more easily be simplified and changed than the others just mentioned, as there are pertaining to them very few standard tools; and these are of little value. Should some parts of the Metric system be adopted in this field but comparatively little trouble would occur.

11 There is no question, however, but what an International English and American Commission, as suggested by Mr. Towne, should, if possible, be established, that the whole matter may be worked up with extreme care before any definite legislation is put into effect. Much more careful expert work is required than can be performed in the committee rooms of a Congress or a Parliament.

MR. F. J. MILLER I have regretted that a little more attention was not paid by Mr. Towne and perhaps some others, to the work of a committee that was appointed by this Society to consider the whole subject of the metric system, and to make a report on it. Before reading a small portion of that report I wish to say that I can speak in the highest terms of the conduct of the committee which prepared

it. Our relations with each other were entirely pleasant. We discussed things in a calm and judicial manner at all of our meetings, and I think all the members gave their best attention to the subject. The chairman of the committee was Mr. James Christie, and the other members besides myself were Mr. William Kent and Mr. George Bond. Following is the introduction to the report which I had the honor to write, and which was signed by all the members of the committee after considerable discussion.

1 Legislation designed to compel the exclusive use of the metric system is not desirable.

2 We believe that such legislation could not be enforced in any event so far as transactions between private individuals are concerned.

3 The general government has the power to specify the system to be used in its own work and business, and can require that work done for it by contractors shall conform to any specified measurements or weights.

4 The government cannot compel any one to bid upon its specifications.

5 Recognizing the well settled fact that the consumer does and must pay all necessary costs of production, we believe that if the government specifies such dimensions as will materially increase costs of production, the government and not the bidder will have to pay such increased costs, it being self-evident that a a bidder, not compelled to bid, will not bid except at a price which will afford him a profit.

6 The bill now before Congress is intended to make the use of the metric system compulsory in the several departments of the government, but it cannot make it compulsory in private transactions.

7 We believe there is no force in that class of arguments which consists in taking integral dimensions in one system, translating them into equivalent and therefore fractional dimensions in the other system and then making comparisons. Such arguments can be made as strong for the one system as for the other.

Although in oral discussion, perhaps at times a little heated, some members of the committee may advance arguments or make statements not in accordance with what I have just read, yet it is to be noted that at a time when calmness of mind and deliberation prevailed, this statement of general principles was agreed to and signed by every member of the committee. I believe this statement so signed will stand the most rigid examination and that any argument, by whomsoever put forth, not in accordance with the principles here laid down is fallacious.

MR. GEORGE SCHUHMANN I do not intend to go into any discussion of the scientific merits of the metric system, but having lived in Germany before, during, and after the time the metric system was put in force there, having worked in a shop where both English and metric measurements were used side by side, and in addition thereto having used the English system in almost daily practice for over

thirty years, I want to confine my f to cal side of the question only, and at the same ti give expression to my opinion, based on these many years of actual experience, that for the average daily practice the metric system is m ch easier on a man's mind, and a still greater mental labor saver to ose who have to calculate much in volumes and weights, moments of inertia, etc. I also wish to state that the fears of most of the an i-metric advocates of the terrible confusion and enormous loss of mo y that would result if the metric system was introduced here, are very much exaggerated.

2 All admit that it would be a esirable condition if the weights and measures of all civilized nations were alike, and no reasonable mind could expect the metric countries to give up their rational system for the English system, no more than one could expect this country to give up its decimal system of dollars and cents and return to the guineas, pounds, crowns, shillings, pence, and farthings of England.

3 Much ado has been made by the antis that in metric countries some of the old measures are still in use. But what of it, if they are? Do not condemn the rule on account of a few exceptions. Let the jeweler sell his diamonds by the carat and let the textile worker spin his yarns by the yard, but do not let that hinder us from abolishing the various sizes of barrels, gallons, bushels, pecks, cords, perches, hundred-weights, long, and short tons; the rods, chains, feet and decimal fractions of feet by civil engineers; the feet, inches, and vulgar fractions of inches by mechanical engineers, etc., etc., while the chemists, electricians and scientific men are already contentedly using the metric system.

4 I have no doubt that some of the old terms would also survive for many years in this country. The farmer would very likely continue to sell his peaches by the "basket," his strawberries by the "box," and measure the height of his horses by "hands." But this will not confuse the metric system any more than the English system, since it has no direct relation with either of them.

5 The firm I am connected with manufactured and shipped last year about 15,000 miles of tubular goods in the shape of wrought iron pipe, boiler tubes, etc., and every length of this had to be measured in feet and inches and then added by the tally clerks. On most goods we ignore fractions of inches, or else the job of adding would be still more complicated. If this same work were done by the metric system, giving the lengths in centimeters, it would be much nearer to the actual length and require considerable less mental work.

6 While some new gages would be required, most of the existing

ones for inter-changeable work could be retained and simply be re-christened into metric terms if so desired. Much stress has been laid upon the fact that all the English dimensions cannot be expressed in metric units without going into many decimals, but for all practical purposes a few decimals will answer, and in most cases can be omitted altogether. The circumference of a circle in proportion to its diameter cannot be expressed exactly in figures, and still for all practical purposes 3.14 is good enough.

7 Many U. S. standards are only nominal sizes anyway. A 3-inch turned shaft is generally $2\frac{15}{16}$ inches in diameter. A 2-inch dressed plank is supposed to be made of lumber which was 2 inches thick before it was dressed, leaving it about $1\frac{3}{4}$ inches thick when finished.

8 The wrought iron and steel pipe sizes are only nominal. They are supposed to express the inside diameter of the pipes, but that is only up to 12 inches. Above that it means the outside diameter; and all boiler tubes are also measured by the outside diameter. A $\frac{1}{2}$-inch pipe has a hole of practically $\frac{5}{8}$-inch, while a 1-inch double extra heavy pipe is less than $\frac{5}{8}$-inches inside diameter, but it is explained that the outside diameter of the 1-inch double extra heavy pipe is the same as the so-called 1-inch standard pipe, which is supposed to have a 1-inch hole, but which actually is about $1\frac{1}{16}$ inches.

9 When the question of uniform pipe threads was up before this Society twenty years ago, all the pipe manufacturers of this country claimed that they had made their gages exactly to the figures given by the Briggs formula and still their goods did not inter-change with each other. At the suggestion of this Society's committee each manufacturer sent samples of pipe, threaded according to their gages to the Pratt & Whitney Company of Hartford, Conn., so as to have them compared with the gages which the Pratt & Whitney Company had made with great care to comply exactly with the Briggs standard. Some of the samples varied as much as six or seven threads; *i. e.*, the pipe of the one manufacturer would screw from six to seven threads farther into the Pratt & Whitney Company gage than that of another manufacturer. (See Vol. 8, page 32, Trans. A. S. M. E.) The consequence was that nearly all the pipe manufacturers of this country purchased new gages from the Pratt & Whitney Company, which were exact duplicates of each other and the interchangeability of all pipes of different manufacturers was very much improved.

10 All these gages can be, or, in fact, should be, retained, because from a practical point of view the American standard for pipe threads is superior to the English or other European pipe threads, on account of the greater taper. All that would be necessary would be to call

the old gages by the approxi e Of course, it would also be desirable that the lish pipe threads, as well as bolt and nut threads, should be in u angeable with the United States standards, but that they are ; interchangeable now, is not the fault of the metric system.

11 With the pipe threads ing, according to the old standards, it would not be necessary to ear the old gas pipes out of the houses or ceilings to fit a new chan delier, as had been hinted in some of the previous discussions.

12 It would also be unnecessary to relay our railway tracks and rebuild the rolling equipment. All we have to do is to call the track 1436 gage instead of 4 feet 8½ inc es. Air brakes, hose couplings, car couplers, etc., could all remain exactly as they are now.

13 Mr. Towne fears that 95 per c nt of the present army of government clerks would be disqualifi for a long time from doing efficient work if the metric system w in duced here, but I believe that he is doing the government c injustice. I have seen the metric system introduced in an Ameri machine shop so as to produce work according to metric dimen . The workmen were all Americans who had not used the m c system before, and in a few days they had thoroughly mastered it—at least as far as their work was concerned—and I should think that the government clerks would be able to do as well as machinists.

14 I am well aware that a change of this kind cannot be made suddenly. In Germany the schools had prepared the younger generation for it some years in advance, and when the change finally did come it caused comparatively little confusion. The old carpenters and other old mechanics who had used the foot rule all their lives naturally were somewhat slow to e the new system, while most of the machinists, on account of t using smaller fractions, took to the metric system very quickly.

15 The younger people had patience and tolerance for the old people's habit of calling things by their old names, and as they understood what was meant, no confusion was caused thereby. It was very similar to the practice which I remember to have been in vogue in New York and Long Island about thirty years ago when the old inhabitants would use the word "shilling" in speaking of values, not the English shilling of 24 cents, but a shilling of 12½ cents. They would even prefer to say eight shillings rather than one dollar. I do not suppose that any merchant made his calculations or kept his books on the shilling basis, prefering no doubt the decimal system of dollars and cents, but this did not prevent him from doing business with the

old folks, if for the sake of sentiment or from force of habit they would call for twelve shillings' worth of goods, nor did it cause him any serious mental calculation.

16 I well remember when working in a machine shop in Germany, we used the Whitworth taps and dies for bolt and screw threads and called them by their English dimensions without in any way interfering with the use of the metric system for the other work. I understand that these screw threads are still made according to the same Whitworth standards but are now called by their nearest dimension in millimeters instead of fractions of inches; this points the way how easy it will be to maintain existing standard gages, including Mr. Towne's lock part of 0.51 inches without interfering with the use of the metric system for general purposes.

17 On the other hand, consider the advantages of the metric system to the vast army of draftsmen. There does not appear to be any fixed rule with the English system in regard to figuring drawings. Some mark 1′10″ while others will mark it 22″, and I know of expensive errors made on account of reading 22″ instead of 2′2″, and other similar misreadings. Such errors are practically impossible with the metric system, as the misplacement of a decimal point makes the error so obvious that it is easily discovered.

18 Metric drawings are generally made to one of the following scales:

Full size, half size, 1 to 5, 1 to 10, 1 to 20, 1 to 50 or 1 to 100; all of which can easily be measured with an ordinary metric rule. Compare the attempt of measuring with a common English rule some distance on a drawing $\frac{3}{32}$″ to the foot with the ease of doing the same thing with a metric rule on a drawing 1 : 100.

19 I am very much surprised to learn that so many influential members of this Society have such a great fear of, and are so strongly opposed to, the introduction of the metric system. I can only assume that they are unfamiliar with the practical use of it, for I am sure that if they would cultivate a closer acquaintance with the beauties of the metric system in actual use their opposition would soon fade away. The metric system is bound to eventually supersede all other systems of weights and measures. I do not mean to say that this will happen in the near future, as it appears that the majority it not ripe for such a step just yet, but another generation will take it up—one that will consider this matter with less prejudice and less fear—a generation of engineers who will not hesitate to temporarily inconvenience themselves, and even go to a little expense in order to make

the work of draftsmen and mechanics and, in fact, of all people who have to calculate in weights and measures, less laborious.

20 The rapid growth of electrical equipment is making it more and more necessary for the mechanical engineer to familiarize himself with electrical science, just as a knowledge of chemistry is indispensable to the metallurgical engineer, or that of geology to the mining engineer and civil engineer. Since all electrical units are based on the metric system, and since the chemists and scientists all over the world are using it now, I know of no better medium than the metric system to facilitate the acquisition of that knowledge which is necessary to the engineer to enable him most effectively to adapt the achievements of science to the use of mankind.

MR. SAMUEL WEBBER I cannot too strongly emphasize the great pleasure and satisfaction with which I have read Mr. Towne's admirable and exhaustive paper on Weights and Measures. I have spent the greater part of a long lifetime in the use, examination, and determination of these subjects and Mr. Towne has given his views on them so clearly that it leaves but very little comment to be added. I can only hope that such a commission as he suggests may be guided by a continuance of the old Anglo-American standards of the foot and pound.

2 The "foot pound" as established by James Watt is the basis of a large part of our dynamics, and any change to such an uncouth expression as a "kilogram meter" would be a great blunder.

3 With regard to measures, the whole continent of North America is laid out by them from the feet and inches of house lots in New York and San Francisco to the acres or miles of every western ranch or railway.

4 Some minor changes in measures of capacity might be advisable. The American gallon could be conformed with that of Great Britain and made ten pounds; the pint, according to old usage, one pound, and two pints a quart. Instead of a quart the gallon could become a component part of a bushel, although the value of the latter measure, in all grain and vegetables, is now usually expressed by its weight in pounds.

5 There is, however, another subject which I think might well be considered by the same or a similar commission and that is our coinage. Our unit of value is expressed by the old Spanish "milled dollar" and is said to contain a certain number of grains of gold. Now if this number of grains of gold were reduced about 3 per cent, our half eagle or five dollar gold piece would be of equal value of

exchange with the British sovereign or pound sterling. The silver dollar would correspond to the French five franc piece, while the quarter dollar would agree with the English shilling and the German mark. This would simplify the rates of exchange materially, and while it would necessitate a fresh coinage of our gold currency, our present silver coins are of such inflated value that they might be retained in use without difficulty or detriment.

6 Though this matter is not strictly pertinent to the subject, I beg leave to offer the suggestion for consideration should any such commission be appointed.

7 I do not feel sure after reading the discussion offered by other members of the Society that such a commission is desirable, but offer these suggestions in favor of a more perfect agreement on these points among the English speaking people, who in population and power are taking the lead among other races of the world. The statistics submitted by Mr. Halsey, show the general popular disregard of the laws making the metric system compulsory, and it seems to me, that adherence to the old Anglo-American standards, somewhat modified, as suggested, is in the course of events bound to supersede the somewhat imaginative French system, forced into use by Napoleon, under entirely different circumstances, and which after all, is based on a decimal division of the old duodecimal system of astronomical and geographical measures.

MR. L. D. BURLINGAME No matter how much opposed we may be at the Brown & Sharpe Manufacturing Company to the adoption of the metric system, and how much inclined we might feel to believe that its compulsory use would be disadvantageous to our country, we recognize that a discussion like this should be judicial in its character rather than partisan, and that it should be open to full debate and that we should attempt to get at the truth. That is, we would not object to the appointment of a commission that was entirely competent and unpartisan, although it has been suggested here that such a commission could not be brought together. If it could, we see no objection to its being appointed by the President, for an investigation.

2 We feel that the Bureau of Weights and Measures has been the proper place for such work to be done. We have urged that they take up the matter of simplifying our weights and measures, and especially to try to bring about uniformity between America and Great Britain, and this is one of the things that a commission, such as is advocated, might take up. We have failed to make any impression so far on the Bureau of Weights and Measures. They have taken a

partisan position and we do not [illegible] g the help from that direction. It would seem as if from some source of authority there should be steps taken that might bring improvement in these minor details, and in points n[illegible] o[illegible] n to criticism in our present system, I see no reason why [illegible] American Society of Mechanical Engineers should be seriously [illegible] posed to any fair minded discussion or presentation of the case.

MR. JESSE M. SMITH I wor[illegible] over three years with the metric system, and I found it most sim[illegible] nd convenient. It has been said that quite a number of coun[illegible] including France, which are supposed to be using the metric sys[illegible] m, do not use it. I have been abroad a good deal, and I have been in several different countries where the metric system is supposed to be used and is used. Summer before last I was in Austria where it is supposed they do not use the metric system, but I found all t[illegible] mountain roads and the country roads that I traveled over were [illegible] sured in kilometers, and Austria is not supposed to be very pr[illegible] ve in that line. I took occasion to ask a number of Austria [illegible] w[illegible] ther there was any difficulty in passing from their old system of [illegible] asurement to the metric system, which they have had for the last fifteen years. They said that they had trouble during the first two or three years, but none after that, and now the old system is practically forgotten. This reminds me of my own experience in Paris about thirty years ago, where the fruit women pushing carts in the streets would sell you grapes or cherries by the *livre* or half-kilo, and take pay in *sous* or centimes as you wished.

2 The significant fact remains, that notwithstanding the vigorous propaganda by some persons [illegible] inst the metric system in this country, that system marches s[illegible] lily onward.

MR. SAMUEL S. DALE[1] The decision as to the creation of a commission must depend on what questions are to be referred to it, and who are to compose the commission. On some issues there can be no compromise, and of such is the compulsory introduction of the metric system into the United States, which Mr. Towne proposes to submit to a technical commission. This is what makes it impossible for an opponent of the metric system consistently to favor that commission as a practical proposition. To do so would be to admit that we are

[1]Non member. Invited to participate in the discussion at the suggestion of the author of this paper.

wrong. Now nothing seems clearer to us than that we are right, and for that reason we are unwilling to submit the vital issue in this metric question to the decision of any commission except one composed of 90,000,000 Americans. The metric fallacy having been established, the question now is not whether compulsory metric laws should be placed on the statute book, but rather how such laws can be kept off the statute book. That is the logical and sufficient reason for our opposition.

2 But if, in order to consider in detail the points raised by Mr. Towne, we should for a while assume that the question is still an open one, then we have only to turn to his fair minded and able argument to find a statement of most convincing reasons why the commission should not be created.

3 In this discussion we can ignore the particular metric proposition that has been pending for four years in Congress, first as the "Shafroth" and then as the "Littauer Bill," each providing for the compulsory use of the metric system for government work. That proposition is now dead, but if it were not any one of the fourteen objections summarized by Mr. Towne in paragraph 73 would be sufficient to kill it. No commission is needed to bury it.

4 Turning to the other points raised by Mr. Towne, let us first consider the personnel of the proposed commission, the character of which is thus described:

> A commission is needed which should be composed of men of training, experience, and recognized authority in all of the many lines of industry, commerce, and science which are involved.
>
> Its members should approach their work with open minds, unprejudiced and untrammeled, solicitous only of learning the facts, of weighing all arguments, of hearing all interests, and of reaching conclusions which shall be sane, just, sound and permanently right.
>
> A commission is hereby created, to be called the commission on weights and measures, which shall be composed, in the discretion of the President, of not less than nine nor more than fifteen commissioners, to be appointed by the President, by and with the advice and consent of the Senate, and to be selected from various professions and pursuits and in such manner that, as far as practicable, every important interest, particularly scientific, industrial, agricultural, commercial, mechanical and maritime interests shall be represented thereon.

5 The truth of some propositions is so evident that it only obscures it to attempt a demonstration. Of such are the following:

a That no fifteen men ever lived who fulfilled the requirements of the Lilley bill;

b That if they were found the market value of each would be nearer a million than three thousand dollars a year.

6 Now for the sake of further consideration of this commission plan, let us assume the impossible, that a commission meeting the ideal requirements has been organized. What, according to Mr. Towne's own statement of the case, are the conditions that confront it?

No country in the world, except the United States and the British Empire, now has complete uniformity in its weights and measures.

Measured either by industry or by commerce, the English units of measurement are in use today at least as extensively, and probably much more so, than those of the metric system. Measured by colonizing and assimilating power, the Anglo-Saxon race, which uses the pound, gallon, and foot as its standards of measurement, far outranks all the countries which use as their standards the kilogram, liter, and meter combined.

To change the unit of length would be to substitute variety and confusion where now we have absolute uniformity throughout the Anglo-Saxon world.

As stated by John Quincy Adams, in his ever-memorable report of 1821, on tha question of adhering to our present system or adopting the metric system, "The first position which occurs as unquestionable is, that change, being itself diversity and, therefore, the opposite of uniformity, cannot be a means of obtaining it, unless some great and transcendent superiority should demonstrably belong to the new system to be adopted, over the old one to be relinquished."

Certainly this comparison (of the English and metric systems) fails to show any marked preponderance in favor of metric units; if anything, it would rather prove the reverse.

Measures of length are linked irrevocably to the past. They exist, they are imperishable, and many of them never will nor can be changed so long as the things to which they apply shall endure.

7 With these statements we are in complete accord and, consequently, are not willing to consider the abandonment of our present priceless uniformity and to plunge into endless confusion by attempting the impossible task of displacing an established system of weights and measures by a poorer one.

8 Mr. Towne's reference to the example set by France and Germany seems to me particularly unfortunate for his argument. Both countries had confusion of weights and measures, which forced them to seek unification. We have uniformity and there is every reason why we should protect it. Their object was to find what we possess. It is ours to defend the possession of what they never have found. We read the official French confession of metric failure in the letter of M. Gaston Doumergue, French Minister of Commerce, Industry and Labor, dated April 11, 1906. These are the reasons why we will not compromise with confusion by referring to a commission the question of compulsory metric legislation in the United States.

9 Now having stated what should not be done, let me outline briefly what we think should be done. The greatest danger to our

established standards lies in popular ignorance. This ignorance is largely due to the fact that scientific men, being practically the only people using the metric system, have favored its use not only for themselves, but for every one else. It has become the fad of schools and colleges. For years (thirty-five to my knowledge) the minds of children have been trained to believe in it as the only scientific system certain to become universal. Children leave school imbued with the metric fallacy. Why? "Because my teacher says so." Editors of newspapers, knowing practically nothing about the subject, have aped the schools and colleges, taught the fallacy and increased the ignorance.

10 In the encouragement of the popular ignorance lies the chief danger to our established standards. The remedy? Free discussion, and if any legislation is required let Congress, pass a law providing that John Quincy Adams' report of his investigations, begun in 1817 with an inclination in favor of the metric system, and finished in 1821, shall be printed at public expense; that a copy be placed in every public library in the United States; that it shall be kept constantly in stock for free distribution to the public; that every President, Senator, and Congressman, shall receive a copy with a recommendation that it be read before passing upon any measure affecting the weights and measures of the United States. That alone would make compulsory metric legislation forever impossible.

11 The next danger to our established standards is the persistent efforts by bureau officers at Washington to discredit the English system and extend the use of the metric. Their acts in this direction are notorious. The National Bureau of Standards from its foundation a few years ago has been made the center of a metric propaganda. It distributes metric charts and metric literature at public expense. Throughout its bulletins there is a constant endeavor to throw discredit on the English system and create the impression that the metric is the only one worth having. From the foundation of our government it has been the settled policy of Great Britain and the United States to maintain uniformity of weights and measures by an exchange of material standards. In recent years, however, the promoters of the metric system in the National Bureau of Standards at Washington have, by a subterfuge, professed that "our fundamental standards are metric." Standards presented to the United States by Great Britain more than half a century ago and which formerly were guarded with the greatest care, have in recent years been discarded as worthless, treated as so much old junk, and exhibited as curios at national expositions. At the same time some metric standards made only sixteen

years ago at Paris have been kept in a vault at Washington under a time lock, guarded as the only fundamental standards of the United States.

12 Nor has the pro-metric agitation of this Bureau been confined to the United States. It is but a few weeks ago that a Canadian manufacturer complained to me that the Bureau of Standards in the Department of Commerce and Labor at Washington was distributing metric charts and pamphlets in Canada. The manufacturers of Canada have their own official metric cabal to contend with. It is only recently that they obtained by a protest the withdrawal of a pro-metric lecturer who was stumping the country at public expense in favor of the metric system. Against the metric propaganda centered at Washington, however, the Canadians are powerless to contend.

13 A still more startling illustration of this pernicious activity came to light last year. A report on American weights and measures prepared by the American representative for the Exposition at Tourcoing, France, stated that "the American pound and inch are larger than those of England." Upon inquiry it was disclosed that the National Bureau of Standards was the authority for this mis-statement, whose only result was to create in France the idea that the linear measures of English speaking countries are not uniform.[1]

14 The supporters of the metric system in the employ of the government are numerous, vigilant, and always on the spot. Their influence is exerted in many ways to discredit our established standards. At this writing there is a plan on foot to secure an appropriation by the United States for the compilation of agricultural statistics based on the metric system. It is in the form of a treaty creating an International Agricultural Institute with headquarters at Rome for compiling agricultural statistics. The supporters of the metric system in Europe have boasted that all the statistics are to be metric, which will make them practically useless to Americans, who are asked to pay for them.

15 It is against this continual pro-metric plotting in the government bureaus at Washington that the efforts of those who believe in defending our established weights and measures should be directed. Recent events have greatly improved the situation there. The Coinage Committee of the present House, which was in favor of the metric system when organized, is now on record against it. Practically all the members of the House, who in the 58th and 59th Congresses have supported the metric proposition, giving aid and comfort

[1]In this connection see letter from the Director of the Bureau of Standards at the end of the author's closure.

to the pro-metric lobby, will be missing from the 60th. It is as certain as anything in Congress can be, that compulsory metric legislation is impossible in the United States. The people who do most of the measuring and weighing in the country do not want it and will not have it. This fact should be made so clear that no one can mistake it. A consideration of Mr. Towne's plan can only obscure it. To his question, "We now have uniformity. Should we not hold it as a priceless treasure?" let the reply be an unmistakable "Yes."

THE AUTHOR In reviewing the discussions of this paper I note two significant facts: (*a*) that in each case the argument is usually partisan, either strongly pro-metric or strongly anti-metric, and (*b*) that where anti-metric it deprecates further agitation because not only useless but dangerous. Both facts tend to strengthen my plea for the reference of the whole question at issue to a competent *technical commission*. No avowed partisan is qualified to adjudicate a disputed issue; no disputed issue can permanently be disposed of by the suppression of discussion. For eighty years the question of adopting the metric system in place of our present system of weights and measures has been under discussion without result, except the Act of July 28, 1866, legalizing the use of the metric system; previous failures have never deterred the advocates of the proposed change from returning to the attack, and will not deter them in the future; Congressional committees have been tested again and again, and have established their unfitness for solving a problem so vast in scope, so vitally important, and so inherently technical. Both sides desire a final decision. The leaders on each side should welcome a decision by a competent, but impartial tribunal, and should now join hands in an earnest effort to secure the creation of such a tribunal and the reference to it of the whole question at issue. To question our ability to secure a commission which shall be both competent and impartial is to question our ability for self-government. Doubts on this point may be dismissed as unjustified by all past experience and as unworthy of our people.

2 Nearly all of the arguments adduced in the discussions are based on engineering experience; some favoring, but more opposing, the adoption of the metric system, but it should be kept in mind that engineers, while vitally concerned, do not represent the only, nor even the chief interest involved; that each and all of our great industries, including agriculture, mining, manufacturing, transportation, and commerce, by no means omitting science in all its branches, are equally concerned and equally entitled to consideration; and that, above all,

the greatest interest involved is that of the plain people in the innumerable transactions of their daily life.

3 Perhaps the most regrettable note in the discussions is that of intemperateness; the implication in each argument that it is infallible; the attempt to belittle the metric system by calling it "the metric fallacy;" the disposition to see one side only of the case, and, in general, the absence of the judicial spirit. Not in this direction lies our best hope of a wise and lasting solution of the question. Mr. Dale says, "there can be no compromise"—but this may be the rallying cry of the pro-metricists as well as of the anti-metricists. What each should seek is a solution which shall be best not for any one interest but for *all interests*, for the American people, and which, being best for all, shall be final. In a case of this kind we should at least try to ascertain what measure of compromise may be available before rejecting all suggestion of compromise. The only such suggestion in the paper under discussion is that, to assist in a final choice between the metric and our present system, we should first ascertain what it may be feasible to do to simplify and improve the latter.

4 With Mr. Dale's eulogy of John Quincy Adam's report, of February 22, 1821, and his suggestion that it should be reprinted and widely distributed at government expense, I am in hearty accord, but I must dissent from his sweeping accusation that the National Bureau of Standards is "the center of a metric propaganda." Having recently visited the Bureau, and spent a long afternoon there with its able head, Professor S. W. Stratton, I am prepared to state that its action has been limited to preparing and issuing revised and accurate comparative charts of the two systems; that its splendid facilities are wholly being utilized in other work of the highest usefulness; and that its present chief executive will loyally accept and enforce any decision respecting our national system of weights and measures which may finally be made by whatever tribunal may be authorized to pass thereon. In much of the purely scientific work of research in which it is engaged, the Bureau finds it convenient to avail of the metric system, and therefore properly does so.

5 Mr. Webber's suggestion that the proposed Commission, if created, should be authorized to include in the scope of its investigations the question of slightly changing the basis of our monetary system, so as to bring it into harmony with the pound sterling and the franc, is interesting and pertinent. I can see no objection to this, but many advantages. So also as to Mr. Oberlin Smith's suggestion that the Commission should be authorized to consider the feasibility and expediency of revising our system of notation—I can see no

objection to thus enlarging the scope of the investigation, and it is conceivable that some good might result, even if only by deciding that such a change is impracticable. The question is thoroughly germane to the main issue, even if somewhat academic.

6 Mr. Suplee has made a valuable contribution to the discussion by giving the French law of July 4, 1837, which covers the final adoption of the metric system, and Mr. Halsey further illustrates the fact that in the so-called metric countries the old measures still remain those chiefly used by the common people in their every day transactions. Rear Admiral Melville, in an admirable review, expresses doubt as to the possibility of securing a non-partisan commission, but to admit this doubt would be to question our ability for self-government. The work of the Commission would be to investigate and report on facts; action on its findings would still rest with Congress, and the latter represents the people. As Mr. Christie points out, heretofore a "stable foundation" has been wanting for proposed legislation, and, it may be added, is equally needed as the basis for a decision to reject definitely the metric system. Still more is the work of the proposed Commission needed to formulate the possibilities outlined by Professor Kent of improvement in the details of our present system.

7 This discussion, like others preceding it, has shown an overwhelming preponderance of opinion among engineers against the adoption of the metric system, and also, but with less emphasis, a contrary view on the part of scientists and instructors. Each group undoubtedly knows what is best for its own purposes, but neither should seek to lay down the law for the other, nor forget that many other groups and interests are equally concerned and have an equal right to be heard.

8 It is true that the work of the engineer, especially that of the mechanical engineer, underlies all of our productive industries, and provides the implements, machines, and motive power by which they achieve their results, and that, therefore, the views of engineers, collectively, may be entitled to greater consideration than those of any other group, but those views, to prevail, must appeal to and be accepted by the many other interests concerned. A clearing house, for the free interchange of views and experience, is needed; can it be provided in any better way than by the proposed Technical Commission?

9 Another fact made clear by the discussion is that our present system of weights and measures is overlaid with many needless and some obsolete multiples and sub-multiples of its basic units; that it

could easily be reconstructed on simpler lines without disturbing its basic units; that in doing this it could undoubtedly be decimalized largely if not completely; that in doing this also its units could probably be brought into more effective relations to each other; and that possibly their relation to the metric units, in some cases at least, might be made more simple and direct. Until these possibilities have been exhaustively studied and definitely formulated, it is impossible for anyone intelligently to pass judgment on the feasibility and expediency of modifying our present system, or of abandoning it in favor of the metric system. To do this would be the work of the proposed commission. In the accomplishment of that work it could and should be greatly aided by the coöperation of the National Bureau of Standards, the facilities of which should be placed at its command for that purpose. Constructive legislation, based on the findings of the Commission, would still rest with Congress.

10 In closing the discussion I beg to point to the fact that the agitation of this question has now continued for over eighty years; that it is as far from solution now as at the beginning: that the agitation, as it is prolonged, becomes more acute, not less; and that all attempts to find a solution by means of Congressional Committees have proved abortive and fruitless. Therefore, I maintain, it is time that we find some better and more promising method whereby to study and to solve this important national problem. Is there any known method better than the creation of a special Technical Commission? If so, it should be presented and discussed. If not, that method should be availed of and should have the loyal support of all, whatever may be their individual opinions and preferences as to what should be the findings of the commission.

LETTER FROM THE DIRECTOR OF THE BUREAU OF STANDARDS

Since the meeting, the following letter, dated August 1, 1907, was written by Dr. S. W. Stratton, Director of the Bureau of Standards, Washington, in reply to an inquiry by one of the members participating in this discussion. With the latter's permission it is inserted here as containing official information pertinent to the subject under discussion." Dr. Stratton says:

"I do not believe that the statement has ever been made by the Bureau of Standards that the American pound differs from the English pound, as the ratio between the pound and the kilogram accepted by the Bureau of Standards is that found in about 1887 to exist between the international kilogram and the British Imperial pound. This determination was the joint work of the International Bureau

of Weights and Measures, and the Standards Office in Great Britain. Under the circumstances it would be highly improbable that anyone here would have stated that there was an actual difference between the avoirdupois pound in use in the United States and the pound in use in Great Britain, notwithstanding the fact that the fundamental standards of the two countries are different.

In regard to the yard the case is somewhat different. When the value, 1 yard = $\frac{3600}{3937}$ meter was adopted by the old office of weights and measures in 1893 it was the mean of all of the reliable determinations made up to that date. Since then a direct comparison between the British yard and the international meter has been made by the International Bureau of Weights and Measures, and the Standards Office in London. The results of this comparison gave the value of the yard as $\frac{3600000000}{3737701113}$ meter. If this value could be relied upon, it would have to be said that there was an actual difference corresponding to 0.00011 inch in the length of the American and British yards, but successive comparisons made between the British yard and its authentic copies differ by amounts in excess of the difference just mentioned and render the ratio found by the International Bureau and the Standards Office doubtful to the one ten-thousandth of an inch. In fact, it is our opinion that the length of the British yard varies from time to time by as much as the one ten-thousandth of an inch, and for this reason it is useless to attempt to express its value in terms of the meter closer than this quantity. Under the circumstances we prefer to assume that our yard is equal to the mean length of the British yard, and for all practical purposes they are equal.

As the statement has repeatedly been made that the adoption of the kilogram and the meter was the work of the Bureau of Standards, we enclose herewith a copy of the announcement made in April, 1893, by the Superintendent of Standard Weights and Measures, in which notice is given that the meter and the kilogram will henceforth be considered the fundamental standards of the United States."

No. 1135

VENTILATION OF THE BOSTON SUBWAY

By HOWARD A. CARSON, BOSTON, MASS.
Non-Member

1 The following paper or statement has been prepared somewhat hastily at the request of the Society. A considerable portion of the text has been taken, with but little change in language, from reports by the writer to the Boston Transit Commission and nearly all of the pictorial illustrations have been taken from the same reports. It is the aim of the paper to describe the ventilation designed to be effected by fans, without going into the question of the possibly ample ventilation that might usually be effected by atmospheric conditions and by the movement of subway cars.

2 The length of the Boston Subway system at present constructed is about 4¼ miles and may be conveniently divided, for purposes of description, into the original subway, the East Boston tunnel, and the Washington street tunnel. Most of the subway system is for two tracks, but a portion of the original subway is for four tracks.

3 The original subway and the East Boston tunnel were intended for surface electric cars running singly, but two of the tracks in the subway have been for some years used for trains, contrary to the former wishes of the Transit Commission. The Washington street tunnel is intended solely for trains, and on its completion the trains will be taken from the original subway and the subway be restored to its former use, *i. e.*, for surface cars run singly.

4 The general scheme of ventilation by fans in all parts of the system is that fresh air shall enter at the stations or portals and be drawn out from what may be called the traffic tubes at points midway between the passenger stations. Owing to the respective environments of (1) the original subway, (2) the East Boston tunnel and (3) the Washington street tunnel, the conduction of the air after leaving the traffic tubes in these three divisions varies. A description and illustration of the methods adopted in the ventilation of these divisions will presently be given. Before doing so, however, it may be well to give

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indication of the density of passenger traffic. Some idea of this may be had by examining the following figures regarding the total number of passengers per annum, going and coming, at the most important station of the original subway and at eight important steam railroad passenger stations, as taken from the report of the Transit Commission for the year ending August 15, 1899:

Station	Number passengers
St. Louis Union Station, St. Louis	8,000,000
Grand Central Station, New York City	14,000,000
South Union Station, Boston	21,000,000
North Union Station, Boston	23,108,384
Broad Street Station of North London Railway	27,000,000
Park Street Station of the Boston Subway	27,400,000
Waterloo Station, London (1898)	28,659,118
St. Lazare Station of the Chemin de fer de l'Ouest, Paris	43,062,688
Liverpool Street Station of the Great Eastern Railroad, London	44,377,000

The Park street station figures are based on the traffic during the eleven months ending August 15, 1899 (before the introduction of trains), and are estimated from the sale of tickets and from other observations.

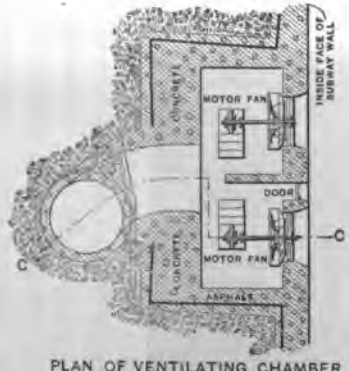
6 It was estimated that at least 50,000,000 passengers used the original subway during the first 12 months after its completion. Its use has apparently increased since then over 60 per cent.

VENTILATION OF THE ORIGINAL SUBWAY

7 In the original subway there are ventilating chambers placed at the side of the tunnel, midway between each pair of stations, and exhaust fans are set in circular openings in the walls that separate the chamber from the traffic tubes. (Fig. 1.) Air according to the scheme of ventilation, which enters at the stations is drawn by the fans from the tunnel and discharged vertically from the chambers, in some cases through grated areas in the street sidewalks and in other cases through low shafts. Some details concerning two of these ventilating sections, which will serve to illustrate the method of ventilating the original subway, follow.

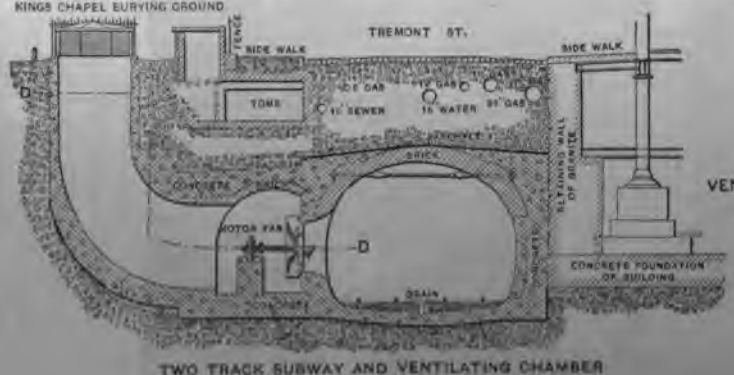
8 The section between the Park street station and the Boylston street station is 4-tracked, its interior width being 48 feet and its height from the base of the rails to the under side of the roof 14 feet 8 inches. The distance between the centers of the stations is about 1250 feet. The ventilating chamber for this section is under Boston Common, nearly opposite West street and midway between the stations. (See Fig. 2.) Fig. 3 shows the low stone building, which

FIG. 1 FAN OPENINGS AND DOOR FROM SUBWAY TO VENTILATING CHAMBERS



PLAN OF VENTILATING CHAMBER
SECTION ON LINE D D.

FOUR TRACK SUBWAY AND VENTILATING CHAMBER
NEAR WEST ST.
SECTION ON LINE B B.

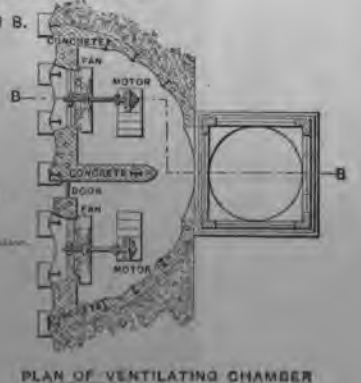


TWO TRACK SUBWAY AND VENTILATING CHAMBER
NORTH OF SCHOOL ST.
SECTION ON LINE C C.

PLATE 2

PLANS AND SECTIONS
OF TWO
VENTILATING CHAMBERS
SCALE

H.A. Carson Chief Engineer



PLAN OF VENTILATING CHAMBER
SECTION ON LINE A A.

FIG. 2 VENTILATING CHAMBER IN BOSTON COMMON

serves as a shaft, over the chamber. This section is ventilated by two fans, each having a diameter of eight feet and a rated speed of about 182 r. p. m. The delivery of each fan is about 49,000 cubic feet per minute.

9 The section between Park street and Scollay square is double tracked, its interior width being 23 feet and its clear height, from the base of the rails to the tie-rods, 14 feet 8 inches. The distance between the centers of the stations is 1450 feet. The ventilating chamber is situated under the Kings Chapel burying ground, a little to the north of midway between the two stations. (See Fig. 2.) The shaft shown in Fig. 4 has an exterior intended to render it inconspicuous.

FIG. 3 SHAFT OVER VENTILATING CHAMBERS

The two fans which serve this section are seven feet in diameter, and have a capacity of about 41,000 cubic feet per minute each at 209 r. p. m. With rates as stated, the air would be changed in these sections about once in nine and six minutes respectively. The stated frequency of change is six times as great as that reported to have been provided for in the most recent London subway, the Baker street and Waterloo Railway.

10 A photograph of a grated outlet over the ventilating chamber at the corner of Washington and Hanover streets is shown in Fig. 5. An inspection of this photograph indicates an obvious objection to an outlet of this class.

FIG. 5 GRATED OUTLET OVER VENTILATING CHAMBER

VENTILATION OF THE EAST BOSTON TUNNEL

11 The general scheme of taking in fresh air at the stations and portals and discharging from the traffic tubes at midway points is observed in the East Boston tunnel. But as it was, of course, not practicable to discharge directly into the outer air from the middle of the harbor, provision was made to conduct the vitiated air to the shores.

12 The duct used in ventilating the harbor portion of the tunnel extends from near Webster street in East Boston to and under the harbor

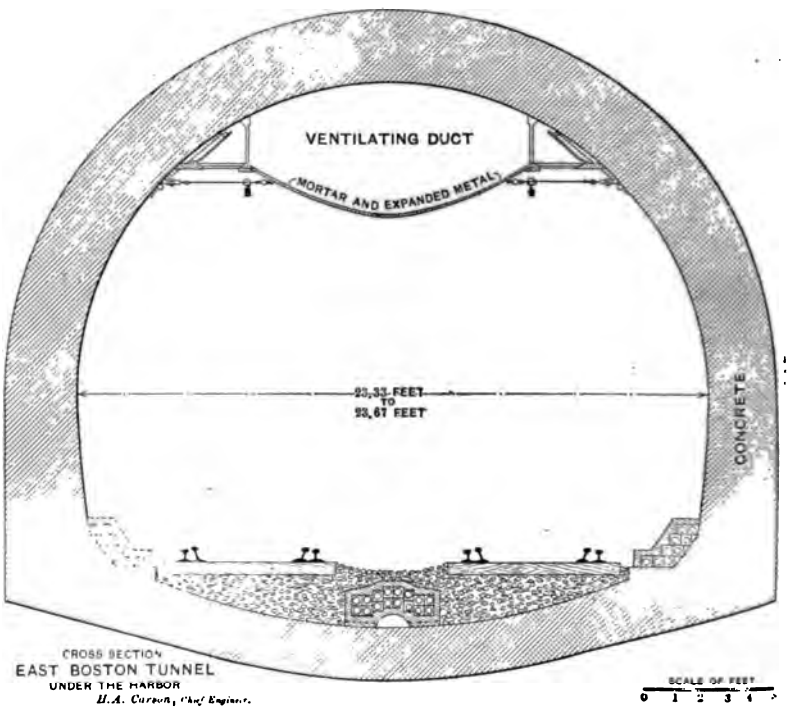


FIG. 6 VENTILATING DUCT

and to the Atlantic avenue station. The duct (see Fig. 6) has a cross-section of about 48 square feet, and is formed in the upper part of the tunnel by means of a diaphragm, one inch thick, made of expanded metal enclosed in cement mortar. This diaphragm is attached to the tunnel walls by steel rods and plates which are themselves encased in concrete. A partition midway between its two ends divides the duct into an easterly and a westerly portion. Immediately on each side of the partition there are 14 openings, each 4 feet long and 1

foot 5 inches wide, through the flat portion of the cross-section of the duct; and at intervals of about 550 feet there are other groups of openings, diminishing in number as they approach the fan chambers. These openings are fitted with doors which can be opened or closed from the tunnel below. So far only the two groups of openings close to the middle partition have been made use of.

13 Fresh air enters the tunnel from the portal at East Boston and also from and through the station near Atlantic avenue, distant about one mile from the portal. This air under normal conditions of fan-ventilation moves to near the middle of the tunnel under the harbor and passes through the openings into the duct referred to above. The air is then drawn to the east and west and leaves the tunnel at the fan chambers at Lewis street in East Boston and at Atlantic avenue, respectively. A diagram rudely indicating the movement of the air is given in Fig. 7.

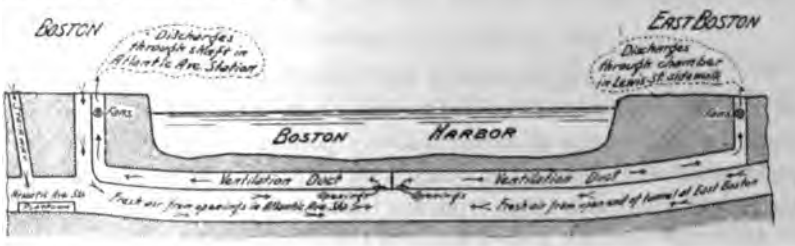


FIG. 7 DIAGRAM (NOT TO SCALE) INDICATING MOVEMENT OF AIR
THE LENGTH OF TUNNEL INDICATED IS ABOUT ONE MILE

14 In the East Boston chamber the air leaves through a grated area 40 feet long and 7 feet 1 inch wide, in the sidewalk. It is intended that the air shall not pass through any part of the gratings of this and other sidewalk outlets at a velocity greater than 3 miles per hour.

From the Atlantic avenue chamber the air passes into a divided duct carried up at one end of the passenger station and is discharged 21 feet above the surface of the street.

15 The ventilating apparatus at the East Boston chamber consists of two single-inlet 8-ft. vertical fans having for normal and maximum speeds, respectively, 175 and 185 r. p. m. and at the Atlantic avenue chamber, two double-inlet 7-ft horizontal fans with speeds of 205 and 218 r. p. m. At the maximum speeds stated the two fans in each chamber, with an input of about 12 horse power to each fan motor, will together exhaust 45,000 cubic feet of air per minute—90,000 cubic feet for the two chambers.

This quantity will give an air velocity in the tunnel of nearly 2½ feet per second and will change the air in the section of the tunnel under the harbor every 15 minutes. Smaller air deliveries can be obtained by running the fans at lower speeds or by running one fan at a time in each chamber.

16 The portion of the East Boston tunnel between the Atlantic avenue station referred to above and Scollay square—the westerly end of the tunnel—is ventilated by means of fans placed in horizontal openings over the roof of the subway and the air is discharged through a chamber connecting with a grated opening in the sidewalk, nearly opposite the Custom House. The two fans, with an input of about 3½ horse power to each fan motor, will each exhaust 20,000 cubic feet of air per minute, which will give an air velocity in the tunnel, toward this centrally placed chamber, of one foot per second and change the air in 1600 feet length of tunnel in 13 minutes.

THE WASHINGTON STREET TUNNEL

17 As in the original subway and in the East Boston tunnel, fresh air is planned to be admitted at the stations and portals and withdrawn from the traffic tube at about midway points. It is not in general practicable to discharge the vitiated air directly into the outer air at the points where it is taken from the traffic tubes; nor is it practicable to discharge through grated areas in the sidewalks, the latter during the day being densely crowded. Air admitted at the portals and at the station entrances and leaving the tunnel at intermediate points will pass thence through specially constructed ducts—in some cases underneath and in others above the tunnel—having a minimum cross-sectional area of about 40 square feet and a length of from 270 feet to 430 feet, to fan chambers. There will be room in each chamber for two single-inlet centrifugal fans, each with a capacity of 20,000 cubic feet or more per minute, giving an average velocity of air in the tunnel of upwards of one foot per second, equivalent to changing the air in each section, say three times every hour.

18 The general movement of the air in the Washington street tunnel is shown in Fig. 8.

19 For specific illustration we may take the platform at LaGrange and Boylston streets. This is 350 feet long and has 15 feet of breadth of stairway at one end and 18 at the other. Air entering the Boylston street station will reach the platform through a stair and passageway. Turning southerly, it will pass through the tunnel to Eliot street, a distance of about 530 feet from the Boylston street entrance. It will be joined at LaGrange street by a current of air

from the entrance and stairway there located and at Eliot street by a northerly current admitted to the tunnel at the southerly portal, 570 feet farther south. At Eliot street the combined volume will pass through openings in the westerly side of the tunnel into a duct below the tunnel invert. This duct, about 370 feet long, will lead the air back, northerly, to and underneath the LaGrange street station, where the air will be extracted by fans and discharged at the back of the station through a shaft having a clear cross-section of 36 square feet and carried to the height of the adjacent buildings.

20 It may be mentioned here that practically all of the stairways and station entrances and exits on the Washington street tunnel are on what was formerly private property which has been taken by the Transit Commission and that all but one of the fan chambers and exits for vitiated air will also be on what was formerly private ground. The one exception is in the middle of Adams square. The discharge in that case will be through a grated opening near the Adams monument.

21 The following table gives additional details of the courses of the ventilating currents of air at various points in the Washington street tunnel.

1 AT LA GRANGE STREET STATION

INLETS FOR FRESH AIR	COURSE OF AIR IN TUNNEL	COURSE OF AIR IN DUCT
South portal. LaGrange street entrance. Boylston street entrance.	Northerly, from south portal to invert duct inlet at A on Fig. 8; about 570 feet. Southerly, from Boylston street station entrance to A; about 530 feet.	From A, northerly under tunnel invert and westerly under LaGrange street station to fan chamber and chimney at LaGrange street station; about 370 feet.

2 AT HAYWARD PLACE STATION

INLETS FOR FRESH AIR	COURSE OF AIR IN TUNNEL	COURSE OF AIR IN DUCT
Essex street entrance. Hayward place entrance. Temple place entrance. Winter street entrance.	Northerly, from Essex street station entrance to arch duct inlet at B on Fig. 8; about 650 feet. Southerly, from Winter street station entrance to B; about 650 feet.	From B, southerly under tunnel arch and easterly under Hayward place station, to fan chamber and chimney near Hayward place entrance; about 430 feet.

3 AT OLD SOUTH MEETING HOUSE STATION

INLETS FOR FRESH AIR	COURSE OF AIR IN TUNNEL	COURSE OF AIR IN DUCT
Summer street entrance. Franklin street entrance. Old South Meeting House entrance. Water street entrance. Old State House entrance.	Northerly, from Summer street station entrance to arch duct inlet at C on Fig. 8; about 550 feet. Southerly, from Old State House station entrance to C; about 900 feet.	From C, northerly under tunnel arch to fan chamber and chimney near Old South Meeting House entrance; about 270 feet.

4 AT SURFACE IN ADAMS SQUARE

INLETS FOR FRESH AIR	COURSE OF AIR IN TUNNEL	
Old State House entrance. Two entrances between Hanover street and Haymarket square. North portal.	Northerly, from Old State Station entrance to fan chamber and surface grating at D on Fig. 8; about 300 feet. Southerly, from north portal to D; about 1430 feet.	No duct.

THE VENTILATION OF ELECTRIC SUBWAYS

22 Most of the subways hitherto constructed have not been provided with mechanical plants for ventilation. One reason for this doubtless is that the air in electrically operated subways without mechanical ventilation is, in general, far better than that of steam operated subways that are so ventilated. Professor S. Homer Woodbridge, who has been consulted for most of the details concerning the ventilation of the Boston system, states that: "A locomotive burning 35 pounds of coal per mile of run produces at a running rate of 15 miles per hour about the same quantity of carbonic gas and of water-vapor as 22,000 average adults in a state of repose, besides emitting an indefinite, though troublesome if not dangerous, amount of smoke, and sensible traces of carbon monoxide and sulphurous gases, to still further vitiate the air. If steam locomotives were to be used in the subway, probably at least 30 times as much fresh air would be required to ventilate it as with electric propulsion."[1]

23 The following table comparing the relative vitiation of the air in the subway at a time when the traffic was large and when no fans

[1]First Annual Report of the Boston Transit Commission, p. 43, for the year ending August 15, 1895.

FIG. 8 GENERAL MOVEMENT OF AIR IN WASHINGTON STREET TUNNEL.

were running and that in various halls, theaters, churches, schools, etc., tends to justify the omission of mechanical ventilation in subways.

	Parts of Carbon Dioxid in 10,000 Volumes	Remarks
Boylston street station, 5 feet above southbound platform	9.45	Samples taken between 5 and 5.30 p. m., on week days in January and February, 1899. One of the fans in the West street chamber is believed to have been running when the third sample was taken. In the other cases none of the fans were running.
Midway between the Boylston street station and the Winthrop school ventilating chamber	6.53	
Park street station, 5 feet above the southbound platform	7.78	
Adams square station, 5 feet above platform	6.62	
Haymarket square station, 5 feet above northbound platform	9.13	
On the street in the central part of the city	4.5 to 5.9	Made at about the same time of year.
In the center of a car on Boylston street about to enter the subway	24.97	Sample taken about 8.30 a. m., February 25, 1899, and car contained about sixty-five passengers. Rear door was opened once or twice while sample was being taken. Forward ventilator was closed and rear ventilator open about one-half inch. Weather clear and cold.
City Hall Council Chamber, two-thirds full	Floor 10.12 to 14.60 Gallery 13.22 to 18.58	
Large public hall in Boston, near open door, with in-draught	13.93	
Another hall in Boston, well-filled	32.59 to 36.43	(the latter being in the gallery).
Four of the principal theaters in Boston	16.16 to 48.7	
Two large churches, Boston and Brookline	12.45 to 18.19	
Twelve schools in Boston, Cambridge, Chelsea, etc.	7.1 to 23.50	

24 The fitness of air in the subway for breathing, however, can perhaps be better ascertained by means of sensitive noses of persons used to fresh air than by the ordinary methods of chemists. Subways contain not only carbonic acid and other matters thrown off from human lungs but have also, widely diffused through the air, dust from the ballast, fine particles of oil from the machinery, and finely ground particles of iron from the brake shoes. All of these are disagreeable and perhaps injurious to health.

25 Another matter, at times more disagreeable than either of the foregoing, is that of the rise of temperature in subways caused by the conversion of a large amount of electric energy into heat. As far as the writer is aware, no particular attention had been given to this question until the summer of 1905 after the opening of the New York subway. A possible alleviative for annoyance caused by the dust, iron, and oil, and the rise of temperature referred to, is a judicious use of an ample ventilating system.

THE COST OF SUBWAY VENTILATION

26 A very rough estimate for the Boston system places the total cost of the ventilating construction, including chambers, ducts, fans and motors, at $125,000, or less than 1 per cent of the combined cost of the original subway, the East Boston tunnel, and the Washington street tunnel. An equally rough estimate of the cost of operation, including power, depreciation, attendance, and interest on first cost, for ventilating the combined system is $14,000 per annum. This will probably be less than 1 per cent of all costs of operation and interest.

The cost does not appear to be prohibitive, and considering experience up to the present time it seems fair to say that electric subways with dense passenger traffic should have fans and motors to supplement the ventilation caused by atmospheric changes and by the movement of cars.

27 It may be well in closing to note that if the passengers in the subway are to breathe pure air the cars should be ventilated as well as the subway itself. The seventh observation in the table on the preceding page shows that the air in a car just about to enter the subway contained more than three times as much carbon dioxide as the average air above the station platforms.

DISCUSSION

MR. CHARLES S. CHURCHILL The Boston Subway holds the unique position of being the only electrically operated subway in the United States that is efficiently ventilated by mechanical means. The writer, in a paper on the "Ventilation of Tunnels," presented to the International Engineering Congress at St. Louis in 1904 (see Transactions, Civ. Engrs., Vol. 54, Part C, pp. 523 to 579), gave a brief description of the ventilation of the original portions of the Boston Subway; and has more recently referred to the ventilating system of this subway as a model in its careful design and execution during construction.

2 It may be further stated, after personal examination of a number of subways in England, France and Germany, that the ventilating system of the Boston Subway not excelled by them in efficiency. Mr. Carson's paper, therefore, is very valuable one as furnishing a complete detailed record of a good mechanical ventilating system of an electrically operated subway, and one that can in principle be followed, not only by existing subways not ventilated as they should be by mechanical means, but also in the case of subways to be hereafter constructed.

3 It should be noted that the ventilation of the recent extension of this subway under Boston Harbor, described as the "East Boston Tunnel," and about one mile in length, is similar in principle to that installed during the construction of the Mersey Tunnel, Liverpool, in 1886, which is about two miles in length, and is now electrically operated. The important difference, however, is that the ventilating duct is carried outside and is entirely independent of the general tunnel section from the center thereof to each end, whereas this duct in the East Boston Tunnel is cut from the tunnel area itself, thereby reducing it 48 square feet, and making it about 20 square feet less in area than the balance of the Boston double tracked sections of subway. It is considered objectionable to reduce the tunnel cross-section in this manner as just so much room for fresh air is lost. Further, the various entrances to the ventilating duct must be opened or closed frequently to suit weather conditions. In a tunnel like this, with an open portal or large opening at one end and a station at the other, not only can the necessity of this reduction be avoided, but also the somewhat indirect handling of fresh air currents, which are interfered with either by passage of cars or by the velocity of the outside air, can be improved. Fresh air may be brought into such a tunnel at the station end without reducing the tunnel section, and from there forced entirely through it at any velocity desired, similar to the plan followed

in ventilating some steam railway tunnels, for example, Elkhorn Tunnel on the Norfolk and Western Railway, Big Bend Tunnel on the Chesapeake and Ohio Railway, and Gallitzin Tunnel,[1] on the Pennsylvania Railroad; but the velocity of the fresh air current required in an electric tunnel will be but a small fraction of that required for a steam railroad tunnel.

4 Mr. Carson, while giving the parts of carbon dioxid (CO_2) per 10,000 volumes of air found in various parts of the Boston Subway when the ventilating plant was not in use, unfortunately fails to give the corresponding figures while the plant is in full operation. This information would be an important and valuable addition to the records of the ventilation of subways; and it is to be hoped that this data will be furnished, so that it may be compared with the following observations made by the writer as to the condition of air in the cars of various European subways that are mechanically ventilated.

NAME OF ELECTRIC SUBWAY	PARTS OF CARBON DIOXID PER 10,000 VOLUMES OF AIR IN CARS	PARTS OF CARBON DIOXID PER 10,000 VOLUMES AIR OF STREET
Metropolitan Railway, Paris	2.94	1.76
Central London, London	5.92	3.55
Great Northern and City Railway, London	2.35	1.75
Mersey Tunnel, Liverpool	4.70	(not taken)
City and South London, London (not mechanically ventilated)	11.78	3.55

The above observations were made in a manner to determine the relative amount of carbon dioxid in the air of subway cars, and that found in the air outside of the Subways; and the efficiency of ventilation may be determined by dividing the part of carbon dioxid found in cars by the amount opposite, which was found in the atmosphere outside of the subway at about the same time. The relative efficiency of ventilation found in this manner may be placed as follows:

Metropolitan Railway, Paris	1.67
Central, London	1.67
Great Northern & City Railway, London	1.34
City and South London, London	3.32

5 Mr. Carson, after comparing the quality of air found in the Boston Subway when plant was not in operation with that found in some of the halls and schools of Boston, and noting from the compari-

[1] See Proceedings American Society Civil Engineers of August, 1906.

son that worse air was found in some of the latter than in the subway, makes the suggestion that this condition "appears to justify the omission of positive ventilation in subways." It should be borne in mind, however, that carbon dioxid is not the only factor that makes ventilation necessary. In schools and halls such elements as dust from ballast, oil from machinery, iron du from brake shoes, and heat from the conversion of large amounts of electric energy, are not present; and these elements alone may make ventilation of subways necessary. That Mr. Carson does not regard such an omission as good practice is evidenced by the fact that the Boston Subway has been mechanically ventilated. The writer doubts if any individual or corporation will argue that because bad air is found to exist in poorly designed structures used by the public, therefore, in the construction of modern buildings and subways the same deg of vitiated air is allowable.

6 There was found a few y s ago in certain public halls and council chambers in London air ich contained 14.9 parts of carbon dioxid per 10,000 volumes. Hov r, newspapers of London very frequently attack subway compani in case air is allowed even to approach this condition. Further, t e Factory Act of England makes 9 parts carbon dioxid (CO_2) per 10,000 volumes of air the maximum in rooms, etc., and the report of the London County Council in 1902 places the safe maximum limit of carbon dioxid in the air of any part of a subway at 8 parts per 10,000 volumes of air, and this applies to the cars in the subways.

7 Inasmuch as a subway car carrying passengers will have 45 per cent or more of carbon dioxid in excess of that found in the general subway air, this requirement signifies that the general subway air should, for the comfort of the patrons and health of the employées of the subway, be maintained so as to contain not more than about 50 per cent more carbon dioxid than the outside air. Dust should also be cared for, and the temperature of the subway should be kept within normal limits. These results, as stated by Mr. Carson, cannot be secured in any subway without positive mechanical ventilation such that fresh air is delivered to all parts thereof, and there should be added to his statement: the total furnished by natural and mechanical means should be sufficient to supply about 30 cubic feet of fresh air per minute to each person in the subway.

8 Mr. Carson very tritely remarks that the sensitive noses of the patrons of a subway readily detect the general quality of subway air. The subway tunnel of the City and South London Railway, which is not mechanically ventilated, and, therefore, is much more heavily charged with carbon dioxid than the ventilated subways of Lon-

don that carry much heavier traffic, was found by the writer, as well as by others, to have a disagreeable odor. The writer in September of this year, while traversing the Rapid Transit Subway in New York, not only personally made this kind of observation, but noted from the expressions of the faces of passengers in the same car that mental adverse comments on the quality of the subway air were being recorded. It is gratifying to note, however, that steps are evidently being taken for mechanically ventilating the New York Rapid Transit Subway.

PROF. S. H. WOODBRIDGE In answer to anticipated inquiry with reference to certain methods and means employed for the ventilation of the Boston subways and tunnel, and which are not fully set forth in the interesting paper presented by Mr. Carson, a few additional statements are ventured which may be of sufficient general interest to warrant attention.

2 Several methods for ventilating the original subway were considered, one being that proposed by an alien engineer who advocated it as a sure, if not the only "positive" method. The method proposed was the reverse of that employed for ventilating the Liverpool-Birkenhead tunnel, namely: a properly proportioned airway built parallel with, and in close proximity to, the subway, with suitably spaced and dimensioned openings between that airway and the subway; the air to be supplied to the airway by a blower placed midway between stations, and the airway extending from that midway point in each direction toward and nearly to those stations. It was proposed by that method to secure a controllable distribution of fresh air along the entire length of the subway.

3 The method was not approved for reasons of cost, both of construction and of operation, and also because of inefficiency in the supply and the unsuitableness of the use of air in ventilating work. The cost of constructing an airway, say four feet in diameter and nearly the entire length of the tunnel, and of connecting that airway at frequent intervals with the subway, would have been large. The power expended in moving, let us assume, 450 cubic feet of air per second through each of the two branches of such an airway, each branch being some 600 feet in length, would be excessive as compared with that required to move the same quantity of air through the same length of the subway having a cross-section of 450 square feet. In the case of the airway, the pressure required would be approximately 4.28 pounds per square foot, which multiplied by the area of the 4 feet diameter airway (12.56 square feet), and that again into the per

minute lineal flow (2160 feet), would give a total of 116,021 foot pounds per minute for each half of the airway between stations. The same air quantity per minute moved through the subway itself would require the very low pressure of 0.0008 pound per square foot, which, multiplied by the area of the cross-section of the subway (450 square feet), and that product by the per minute lineal velocity of flow (60 feet), gives approximately 20 foot pounds per minute as the frictional work; or approximately one five-thousandth of that work found for the special airway method of ventilating a subway. As one of the principal costs of such ventilation is that of the power required to operate ventilating mechanism, that enormous disparity in work to be done by such mechanism in the two cases made it quite impossible to favor the special airway scheme from the standpoint of operating economy.

4 As to the efficiency of the airway method of supplying air to the subway, it will be observed that the entrance of equal volumes of air at intervals of, let us suppose, 100 feet, would normally result in a cumulative movement of air from a point midway between the stations toward and to those stations. Each of the six 100 feet sections of the subway would then receive a supply of 4500 cubic feet of air per minute. If the impurities which vitiate the air of the subway are assumed to be equally generated along its length, the impurity held by the air of the successive sections from the center to the stations would be uniform, and the air encountered by those entering the stations from the outside would be that carrying the impurity out from the subway through the stations and approaches for outboard discharge. The result would then plainly be a uniformity of atmospheric vitiating contents throughout the subway and stations, and approaches to stations.

5 Some of such contents would be taken up by the air within a few feet of the point of discharge, and some of it 600 feet distant from that point and requiring ten minutes of travel to reach the station, having passed through the six intervening sections between the center and the station point, a condition to be presently noticed as one to be avoided. The longer the distance traveled, the longer the time of retention of the organic matter in the air, and the greater the change toward fermentation and decomposition, and the more offensive the attending odor. A movement of air from center toward stations would therefore bring to the stations and approaches the worst of the subway air.

6 In the matter of protection against dangerous situations, as those incident to fire or panic, the method of ventilation by auxiliary

airway supply is as faulty as it has been shown to be in its mechanical features. In the case of the firing of a car within a subway and between stations, the natural rush of escaping passengers would be toward the stations. If the air traveled in the same direction with those in flight, escape from smoke and heat would be less immediate and complete than if the air moved in a counter direction.

7 So also for the prevention of panic at crowded stations, due to a filling of those stations with smoke and heat consequent upon the accident of fire within a subway, an indraft of fresh and cool air from without is to be preferred to an outdraft at those congested points of smoky and heated air from within.

8 A further reason which favors the entering of air at the stations and the removing of air at points midway between stations, is that the air of the subway most breathed is that at the stations by the waiting crowds. Once in the car, if it be of the closed type, the air breathed is that of the car rather than of the subway proper. Furthermore, the change of air within closed cars is chiefly at stations, when doors are open and the passengers are in exit and entrance. The quality of air at the stations is therefore of more vital importance than is that of the subway except when open cars are in use.

9 The maintenance at the stations of the purest air practicable is additionally advisable because of the impression made on most users of the subway by the quick transition made from the outer to the inner air on entering the stations and when the olfactory senses are keen, and any taint in the air entered is quickly detected. If on entrance the air is noticed as repulsive, a mental impression is made which is likely to be persistent, and to magnify and aggravate such defects as actually exist, and to find expression in private and public criticism and condemnation of atmospheric conditions in the subway. If there must be offensiveness to keen olfactories in air escaping from the subway, it had far better be where the boy in the picture stands (Fig. 5), than where patrons enter the subway.

10 Therefore, for the maintenance of the better hygienic conditions in the subway; for the more effective use of air; for the protection of patrons in case of fire; for the prevention of panic at stations; and for the subordinate effect of insuring favorable first impressions on the users of the subway, the intake of air has, in the Boston instance, been made at the stations and the outlet at points midway between them.

11 In general, the minimum quantity of air which the mechanical system for the ventilation of the subway is planned to move is, as has been stated by Mr. Carson, equal to a flow of one linear foot per second

from each station toward each center of discharge. The maximum speed of the fans was planned to be such as to discharge 50 per cent in excess of the minimum quantity named. If the cross-section of the subway is 450 square feet, the minimum per minute air flow through the discharge fan, or fans, between stations should be 54,000 cubic feet, enough to supply 1000 breathers with such reasonably pure air as to give a carbon dioxid increment of less than 2 parts in 10,000 of air. If a rise of five degrees of temperature be allowed, due to the transformation of mechanical into thermal energy, the corresponding rate in horsepower of work so transformed would be 115 between stations. Allowing an average electric input of ten horse power to each car, eleven cars continually running between stations located 1200 feet apart would be provided for.

12 Such, briefly stated, are the reasons for the adoption of the method of using air employed in the ventilation of the Boston subway and tunnel.

13 A few words may be allowed with reference to the type of fan selected for the ventilating work. The two requirements governing the selection of fans for this purpose were, first, a minimum power expenditure, and, second, a minimum noise of action.

14 The choice lay between the standard cased blower type, the uncased radial, and the axial fan. Reference to a few of many tables compiled from the results of an extended series of tests made at the Massachusetts Institute of Technology on the performance of a variety of fans, will aid to an understanding of the reasoning which led to the choice of the type used. The blower type of enclosed fan, and the open and radial types, which were subjected to test, were 36 inches in diameter. The axial fan was of the Blackman type, and 30 inches in diameter, and the tables show results for these fans when run at a speed of 500 revolutions per minute. The areas of inlet to all the fans were practically the same, a part of the experiments having had reference to a determination of the powers required to move air through a given aperture and against various pressure differences by the several types of fans used. While the tables do not apply directly to fans of other sizes, they indicate the law which governs the performance of their respective types and furnish a basis for computation with reference to such performance in fans of any size and run at any speed.

500 R. P. M.

TYPE OF FAN	PRESSURE INCHES OF WATER	VOLUME OF AIR. CU. FT. PER M	HORSE POWER INPUT TO FAN	FT. LBS. PER CU. FT. OF AIR MOVED
Sturtevant Cased Fan	1.60	0	1.09	
Double Inlet	1.685	1000	1.225	40.42
	1.60	2350	1.56	21.90
	1.50	3160	1.75	18.27
	1.25	4600	2.06	14.77
	1.00	5870	2.30	12.95
	0.75	7230	2.65	12.09
	0.65	8400	2.95	11.59
Sturtevant Cone	1.095	0	1.13	
Uncased Fan	1.00	1750	1.28	24.13
Single Inlet	0.90	2800	1.30	15.29
	0.80	3800	1.34	11.63
	0.70	4650	1.43	10.15
	0.60	5375	1.56	9.57
	0.50	6025	1.73	9.47
	0.40	6525	1.88	9.51
Briggs-Meigs	0.893	0	0.42	
(Woodbridge)	0.8	1325	0.575	14.32
	0.7	2425	0.70	9.53
	0.6	3350	0.81	7.95
	0.5	4125	0.865	6.92
	0.4	4760	0.89	6.17
	0.3	5250	0.92	5.78
	0.26	5400	0.93	5.69
Blackman Axial Fan	0.55	0	0.76	
"Forward"	0.50	450	0.698	51.18
	0.40	1400	0.58	13.64
	0.30	2275	0.475	6.88
	0.20	2925	0.383	4.32
	0.10	3425	0.30	2.89
Blackman Axial Fan	0.53	0	0.47	
"Reversed"	0.50	550	0.46	27.60
	0.40	1725	0.40	7.65
	0.30	2750	0.34	4.08
	0.20	3475	0.31	2.94
	0.14	3850	0.30	2.65

15 A cursory examination of the table makes evident the well established fact that the cased radial fan is a superior type for use when air is to be moved against any considerable pressure. No other would have been considered had the auxiliary airway method of ventilation been adopted.

16 The ordinary unhoused radial fans are typified in the Sturtevant "cone" pattern. When that fan is made double inlet, to bring it into correspondence with the double inlet blower fans of the cased type, it will move against a resistant pressure indicated by one inch water column approximately 60 per cent of the air moved by the cased blower of equal diameter, and when run at the same rotary speed. As resisting pressures decrease, however the air moving capacity of this type of unhoused fan is shown to increase, and eventually to exceed that of the housed fan. Furthermore, the per cubic foot work by the uncased fan is nearly double that of the cased fan at the resisting pressure of 1 inch water column, and at the lower resisting pressures tabulated equality is reached, and with indications favorable to the uncased fan.

17 The cased fan is not adapted to low pressure work, for the reason that the pressure existing within the casing itself (and which is potent among the conditions producing flow through the fan orifice), is one against which the impelling fan must work.

18 The form of the Briggs-Meigs type of fan reduces stray, or waste, work, first, by a contraction of the perimeter area to about one-fourth that of the standard cone fan, so preventing regurgitation; and, second, by a form of blade designed to avoid imparting to the air moving out radially through the fan any unnecessary tangential motion. The narrowness of the peripheral opening reduces the volume of flow under any given condition of rotary speed and resisting pressure, but both factors of contracted perimeter airway and curved blades reduce the per cubic foot work to approximately 60 per cent of that expended by the Sturtevant type of cone fan. For higher pressure, the efficiency of the Briggs-Meigs type of fan falls off, as compared with that of the Sturtevant fan, because the curved blades of the former are not as well adapted as are the radial form of the latter to move air against opposing pressure. At a point between pressures of 7/10 and 8/10 inch of water column, the two types are of equal efficiency as measured by the per cubic foot work done in each case.

19 The Blackman fan is the only one of axial type of the performance of which a tabular exhibit is here made, for the reason that this fan when run in a reverse position, that is, when mounted on the delivery side, rather than, as in the regular manner, on the feed side of the aperture, gives both capacity and efficiency results superior to those obtained by any of the several other fans of the axial type tested.

20 It is of importance to note, that the characteristic curve of the radial fan, whether cased or open, would show a minimum energy input to fan when no air is being moved through it and the system

with which it is in connection, and an increasing energy input as the volume of air passed through the fan and system is increased; and, second, that with the axial fan the reverse is found to be true, since for any given speed the less the effective work done by the fan the greater the energy input to the fan; and the larger the effective work the less the energy input, all of which appears less strikingly from an inspection of the numerical tables than it would from an examination of graphical tables, could they be presented with this discussion.

21 Because of the very small resisting pressure against which fans would operate to produce a slow flow of air through the subway as a conduit, and through vent ways from the fans, carefully designed for the purpose of reducing frictional and other resistance to a minimum, the choice of fans was narrowed down to the Briggs-Meigs radial, and the Blackman axial reversed. The subway construction, as well as the admissible dimensions of ventilating chambers, imposed a limit on the size of permissible fans.

22 A radial fan with generous inlet requires about the same wall aperture as that which an axial fan would fill. Thus a 30-inch axial fan fills about the same wall aperture as is required by a 36-inch Briggs-Meigs radial fan.

23 By reference to curves, from which the tables are made up, it appears that under a resistance pressure of 2/10 inch water column, the radial fan moves 5675 cubic feet per minute, as against 3475 cubic feet by the axial reversed. Therefore, at that pressure, the speed of the axial fan would have to become 64 per cent greater, or 820 r.p.m. to make its output equal to that of the radial; and as energy input to fans of given size varies as the cube of speeds, the power would be increased practically fivefold, and would become $0.34 \times 5 = 1.55$ h.p. for moving 5675 cubic feet of air per minute, which would make the cubic foot work nine foot pounds as against five for the radial fan. Furthermore, the noise resulting from such high speed of the axial fan would prove a serious objection to its use. The action of the radial fan of the Briggs-Meigs type requiring the same wall aperture and moving the same air quantity would be unobjectionable.

24 The subject tempts to further elaboration and discussion, particularly in connection with the ventilation of the tunnel, and with computations made (and to some extent unmade) for determining resisting pressures, fan sizes, forms and speeds, and required operating powers; but this contribution to a discussion of the leading paper must close with a protest against the indifferent use to which carefully devised and provided means are at times and in places found to be put, and also against the fouling of subway walls and floors by,

perhaps diseased, and certainly unwholesome expectorators. Inevitably, a subway grows dirtier with age, and in corresponding need of increasingly energetic ventilation if the air within it is to be kept free from offensive and moribific taint. Let subways and tunnels be liberally furnished with illuminated prohibitions against polluting offenses, and let offenders be hygienically dealt with by heroic processes. No practicable artificial ventilation can sweeten a dirty subway.

MR. W. CLIFFORD Assuming the number of passengers at Park Street Station to be 90,000,000 per year, equal to 246,570 per day of 24 hours, or an average of 10,000 per hour, or say 30,000 during the busiest hour of the day, and assuming 100 cubic feet of air per passenger per minute diffused through the station, a ventilation of 50,000 feet per minute would be required at this point.

2 If the efficiency of ventilation alone is to be considered, placing an exhaust fan midway between two stations is a good arrangement, provided the volume produced is sufficiently large to maintain a velocity of current that will carry away the impalpable dust, or even the larger particles stirred up by the moving trains, or ground off the tires of the wheels and the contact shoes of the third rail. A means of automatically increasing the speed of the fan to maintain the fixed normal volume (when increased resistance, through the piston action of meeting trains tends to diminish it), should also be provided.

3 This piston action of moving trains was very noticeable during the limited experiments made by the writer with the fan placed at the top of Hoosac Mountain shaft to ventilate the tunnel. It was found that the water gage, or resistance, varied from 0.36 to 0.8 inches with 394,000 cubic feet of air passing at the former gage.

Size of fan, 16 feet diameter, 8 feet wide.
Revolutions per minute, 110.
Total horse power indicated by meters, 127.
Horse power required to drive jack-shaft when fan was cut out, 96.
Power delivered to fan pulley, 31.
Horse power in the air, 22.6
Mechanical efficiency, 73 per cent.

4 These figures do not bear directly on the subject under discussion, but it was thought they might be interesting.

5 This short Boston subway could easily be ventilated by one installation giving a high standard of mechanical efficiency, say 80 per cent with an electric drive, and in case of a long subway like New

York, one installation could be used to cover ten miles of tunnel to a very great advantage. There can be no objection to high speed of ventilating current where there is already rapid movement of trains.

6 In ventilating mines, the writer frequently recommends their laying out in such a way that the whole ventilating power of the fan can be directed through one split or division of a mine at once, when desired. This often means a current velocity of 60 miles an hour. One hour's application of this hurricane ventilation removes all dangerous dust and more effectually prevents explosions than weeks of expensive water sprinkling. Apart from the nature of the danger, the same principle holds good with a ventilating current of a tunnel.

MR. FRANCIS FOX As the Boston subway is worked electrically, the question of ventilation is greatly simplified, as compared with tunnels in which the products of combustion from steam locomotives have also to be considered.

2 Assuming 30 cubic feet per minute per person as the volume of air required to maintain purity, this being the standard we adopt, I arrive at the following results, which are necessarily only approximate, as I have not all the necessary data upon which to base the calculations.

3 I observe that the traffic in the first 12 months was 50,000,000 passengers, and these have increased in number 60 per cent or 30,000,000, making a total for the year of 80,000,000. Assuming the traffic on Sundays to be one half of that on ordinary week days, we take 340 full days for the year; this gives a daily traffic of 235,294. Assuming that one fourth of this represents the crush hour traffic of one hour duration under the most congested conditions, we obtain 59,000 as the figure representing the maximum number of passengers passing through in one hour.

4 I have no data as to the average time each passenger is in the subway, but I assume it to be eight minutes; this gives 7866 minute-passengers to be provided with 30 cubic feet of air, or a total volume of air required of 235,980 cubic feet per minute.

5 From the paper, I gather that the volume of air being exhausted from the tunnel, and which is therefore replaced by fresh air from outside is 292,000, thus showing that the purity of the air is all that can be desired.

6 In London we have certain electrical railways which are insufficiently ventilated, whilst on the other hand some are over ventilated, insomuch that objectionable draughts are produced, which act as deterrents to some intending passengers.

7 A happy medium between over and under ventilation is what is required, combined with careful observation of the force and duration of the wind outside, and in the Boston subway this can evidently be attained.

8 The ventilating duct in the crown of the tunnel is a satisfactory arrangement in the case of electrical railways where soot has not to be contended with, and as it has a sectional area of 48 square feet for a volume of 45,000 cubic feet per minute, the velocity is not excessive.

9 The author very properly points out that the olfactory organs and the lungs are much more delicate tests as to the presence in the air of certain impurities, than any chemical analysis, and I also note with pleasure his remark that much more attention is required as to the ventilation of the actual cars themselves. I called attention to this question in the paper I communicated to the St. Louis Exhibition Conference of Engineers in 1904. In fact, were the cars and carriages thrown open to the air of properly ventilated tunnels the public would be great gainers.

10 We engineers are constantly striving to attain fresh air, but the traveling public shut themselves up in vitiated air, often of appalling character, by keeping the doors and windows closed.

11 As regards the cooling of the air in tunnels, we have found the greatest advantage in the adoption of fine spraying of water in the Simplon Tunnel. By this means the temperature of the air can easily be lowered by 20 to 30 degrees Fahr., or even more.

12 In conclusion, I am glad to find that the system of ventilation of the Mersey Tunnel, which was carried out in 1880–1886 (and was then described as drawing vitiated air from the tunnel at a point midway between the stations, and which has stood the test of 20 years of experience), has been applied to the Boston subway with so much skill and so much deserved success.

MR. WALTER B. SNOW The original paper and Professor Woodbridge's discussion refer to an air change once in ten minutes and to a flow of one linear foot per second from each station toward each center of discharge. The change of air is sufficient to meet all ordinary conditions, but such a low rate of flow (which is a measure of a vacuum produced) would leave any ventilating system practically powerless to overcome the effect of ordinary atmospheric changes. A difference of only 0.01 inch of water is sufficient to produce a velocity about six times greater than that planned for the subway. What must be the result when large open portals and numerous entrances and exits, to say nothing of moving trains, afford ample opportunity

for the creation of pressure differences much greater than 0.01 inch. Under these conditions the fan becomes merely local in its effect. It is practically powerless to control the direction of currents at such distances as exist in the subway. In a word, so long as the subway connects through large openings with the outer atmosphere, it is impossible for the fans of the capacity here installed to properly control the flow of air. The trouble in the case of this installation is not with the fan, but with its size. The problem is one of volume and velocity, which must be sufficient to insure the maintenance of a pressure difference that cannot be overcome by atmospheric conditions.

DR. G. A. SOPER The writer does not hold the view that the ventilation of the New York and Boston subways without fans has been proved to be a failure and that mechanical ventilating devices are indispensable in subways built near the surface of the ground.

2 If we take for our guide the results of air analyses, it must be admitted that very little is known concerning the Boston subway. The analyses printed in the reports of the Transit Commission and reproduced by Mr. Carson are far too few and, perhaps, Professor Carmichael, who made them, would permit the writer to say, not sufficiently representative to warrant the deductions of far-reaching importance which are now made with regard to them.

3 If, as has been suggested, we cast aside the results of air analyses and trust implicitly to that unreliable sentinel, the nose, we are still more likely to be led astray.

4 The remedy for a bad smell is not always more air. It is often feasible to get rid of an unpleasant odor once and for all by removing its cause. There is no subway anywhere, so far as the writer is aware, where unpleasant odors do not occur and where these odors could not be greatly reduced by closer attention to comparatively inexpensive details of construction and operation.

5 So far as the condition of the air in the New York subway is concerned, Mr. Churchill apparently holds far different opinions from the writer. There are the results of 5000 analyses to show that the general air in all parts of the subway was satisfactory from chemical and bacteriological standpoints before the present changes in ventilation were made. The most objectionable conditions were the heat and odors, and possibly the dust. Of these the heat and odors were the most obviously objectionable; the heat for about four months of the year; the odors continually. Without the odors the heat would be far less noticeable.

6 To meet these difficulties, mechanical fans were installed and blow holes, some of which were provided with check valves. Mechanical ventilation was not, however, the only measure of relief which a careful study of the case suggested.

7 More time and much more careful observation than have thus far been devoted to the subject of subway ventilation are needed before we should speak dogmatically with regard to methods which are both necessary and sufficient for ventilating subways. In the writer's view, the art, if art it can be called, is in its infancy.

8 In considering the condition of air in the New York subway, confusion must not exist between conditions which are general and those which are local. The unpleasant and unwholesome conditions connected with overcrowding at some of the stations and often in the cars are local. In the writer's view it is not improbable that the best measures to adopt to improve these conditions would be local ones.

9 To increase the frequency with which the air is renewed throughout the subway with the hope of relieving the conditions in a densely packed and badly ventilated car is to attack the problem at extremely long range. Especially is this true when the general air of the subway is already good.

10 The writer would like to know what method of analyses Mr. Churchill used when he found 1.75 and 1.76 parts of carbon dioxid in the air of the streets of London and Paris, respectively? These amounts are exceedingly small.

11 Very accurate analyses made in France by Reiset gave 2.96 as the amount of carbon dioxid present in normal air. The records of the Montsouris Observatory at Paris give, as an average of observations covering thirteen years, 3.14. Schultze at Rostock made a daily analysis of air for four years and gave, as his average of all results, 2.96. Angus Smith reported that the air among the Scotch hills contained 3.36; the air of Manchester, 4.03; of Perth, 4.14; of Glasgow, 5.02. Rosecoe and M'Dougall found 3.92 parts of CO_2 in Manchester air. J. S. and E. S. Haldane made the figure 3.0 volumes for country air and G. F. Armstrong, 3.13. Petenkoffer's figure was 3.5.

12 In London, Angus Smith found in the parks, 3.01; in the streets, 3.80; and, as the average of thirty-five analyses of air from different parts of London, 4.39.

13 The most careful long series of analyses of London air were made by Russel who, as the result of one hundred and fifty-nine determinations, announced 4.03 as the average for the center of London. Russel's smallest figure was 3.0.

14 A few years ago, Butterfield was instructed by the committee of the House of Commons to determine as exactly as present scientific methods would allow the actual condition of the air of the debating chamber when in use. In this investigation, the outside air of London, as it entered the ventilating apparatus, was found to contain 3.37 parts of CO_2 with a maximum of 3.74 and a minimum of 3.14.

15 In the writer's investigations for the New York Rapid Transit Commission over 2000 carbon dioxid determinations were made of subway air and air from the streets through which the subway passed, with the result that the average of the results of analyses of outside air was 3.67, with a maximum of 5.61 and a minimum of 2.69.

16 Mr. Churchill's reported findings of 1.75 and 1.76 parts of CO_2 in the air of London and Paris are therefore of considerable scientific as well as practical interest.

THE AUTHOR The ventilating duct in the harbor portion of the East Boston tunnel was made inside the tunnel cross section because a large saving in cost could thereby be made—much more than enough to balance the loss due to the reduced cross section.

2 The cross section after reduction is for each track less than one per cent smaller than much of the New York subway, less than five per cent smaller than the usual Paris and Boston subways, and is far larger than most of the electric subways of Europe.

3 The author had the experience of riding through the Pracchia tunnel in Italy both before and after its ventilation by Saccardo and greatly admires this system and its later applications in this country. There would be some objections, however, to its use in the East Boston tunnel; one being that a station may be arranged west of the easterly portal, not far from the railroad and steamboat stations. In this case the ejected air would have to be blown through the tunnel station.

4 In the 4½ miles of the Boston subway system there are 3 two-track portals and 2 for four tracks, 39 stairway openings averaging about 12 feet wide, 14 generous openings from fan chambers, and some other openings, all to the outer atmosphere.

5 It is therefore not surprising that in breezy weather there are often currents in portions of the subway much greater than can be controlled by the present motors and fans. Observation shows that in each section of the subway the air would frequently be nearly still (except for the movement of the cars and fans) and that at times the air in all portions would be nearly still. The more rapid the currents are the the less need there is for mechanical ventilation, and when the air

would naturally be still fans of the capacity planned for the subway can effect reasonable ventilation. There would be an advantage of course, except as to cost, in the use of more powerful fans, limited only by the comfort of the passengers on the station platforms. Passengers generally seem to prefer vitiated air rather than draughts, and doors and windows of stairway approaches are often closed when as far as ventilation is concerned they would better be kept open.

6 The cars moving in one direction in any particular piece of the subway during operating hours are separated by brief intervals of time and there are as many moving say to the right as there are to the left. This tends to mix the air thoroughly and aid ventilation but may not as a whole cause the fans to do either more or less than their normal work.

7 It must be admitted, as Mr. Churchill and Dr. Soper note, that little information is given in the paper as to the quality of air in the subway. The paper was hastily prepared in response to frequent requests from the Society and all the available analyses of Boston subway air were given. The air in the subway was rarely or never complained of, so far as the author knows, and was sometimes praised, and the matter of adding to the half dozen analyses made seven years ago was apparently not thought of. He is not aware that he based on these analyses any "deductions of far reaching importance." It was merely intended to note that the analyses, as far as they went, tended to justify the omission of ventilating fans.

No. 1136

OBITUARIES

ARTHUR VAUGHAN ABBOTT

Arthur Vaughan Abbott was born in Brooklyn, N. Y., in 1854. After graduating from the Polytechnic Institute of Brooklyn in 1875, he served in the Department of Parks of New York, and in the engineers' department of the East River Bridge, superintending cable construction, and in charge of material inspection. Among his noteworthy inventions and patents were the cable wire splice, wire cutting machinery, and testing machines for steel and cement.

Mr. Abbott was associated with E. T. Fairbanks & Company four years; the Boston Heating Company as chief engineer three years; and with the Daft Electric Light Company as mechanical engineer, where he was engaged in work on the early electric roads. He was also consulting engineer for the Ogden City Water Works, the Bear Canal, and the Waukesha Water Pipe Line.

In 1892 Mr. Abbott took up telephone construction. He was the author of "A Treatise upon Fuel," "Testing Machines," "Telephony," and numerous magazine articles and professional papers.

Mr. Abbott was a member of the American Institute of Electrical Engineers, The American Society of Civil Engineers, and became a member of this Society in 1901. He died in St. Luke's Hospital, New York, December 1, 1906.

FRANCIS RAMSEY ALLEN

Francis Ramsey Allen was born in 1881 in Summit, N. J. He was educated at the Adelphi Polytechnic in Brooklyn and at the Black Hall School in Connecticut, at which place he continued his college preparatory studies and was graduated from Sibley College, Cornell, in 1904, with the degree of M.E. .

Mr. Allen gained his shop experience with Washburn & Moen, Worcester, the Locomotive Repair Shops, Keene, N. H., and Bethlehem Steel Co., Bethlehem, Pa.

He accepted a position with the Niles-Bement Pond Co. and was located at their works in Philadelphia and later in Plainfield, N. J.

He was transferred to the P[illegible] the same company at Hartford, Conn., and [illegible] the general sales force of this company at 111 Broadway, N[illegible] Yo[illegible].

He was a member of the [illegible] fraternity, and was active in college life at Ithaca. Mr. [illegible] in Brooklyn, December 15, 1906.

CHARLES THOMAS BAYLESS

Charles Thomas Ba[illegible] b[illegible] Louisville, Ky., September 2, 1871. He prepared for co[illegible] at L[illegible]isville Rugby School, and later entered Stevens Insti[illegible] T[illegible] in[illegible]y, receiving the degree of M.E. with the class of 1893. He [illegible]structor during the supplementary term at Steve In[illegible]tute[illegible]; and was with Mr. David L. Barnes, consulting engi[illegible]r, of [illegible], 1893–1896. He went to New Mexico in 1896, as chemi[illegible] in t[illegible]elter at Chloride. He entered the employ of the Mexi[illegible] Cen[illegible]ilway, City of Mexico, in 1897, as draftsman in the m[illegible] ve p[illegible]r department. In 1899, he was made chief draftsman, and [illegible]mber 1, 1901, was appointed mechanical engineer. While t[illegible]e, he had charge of design and equipment and general railway work. He was a member of the Railway Club of Mexico, and became a member of the Society in 1896. He was a member of Beta Theta Pi and Theta Nu Epsilon fraternities, Past Master of the Toltec Lodge No. 214, Free and Accepted Masons, City of Mexico, and a member of the Royal Arch Masons. Mr. Bayless died September 5, 1906, in Aguascalientes, Mexico.

CHARLES ADDISON BRAGG

Charles Addison Bragg was born in St. Louis, Mo., in 1850, and received his early education in St. Louis schools, graduating at the Union High School of that city. He prepared for college at Stamford Institute, Stamford, Conn., and subsequently attended Yale University.

Mr. Bragg did his first shop work in St. Louis and Philadelphia with the Globe Shot Co., with whom he later became manager and superintendent. He was the inventor and patentee of the method of manufacturing shot by which the shot instead of being dropped through the air dropped through a jet of steam which afforded a more rapid rate of cooling and reduced very materially the height of the shot tower.

He became associated as constructor and salesman with the United States Electric Lighting Co. in 1882, and was one of the pioneers in electrical work. In 1889 he became connected with the

Westinghouse Electric and Manufacturing Co. as manager of the Philadelphia office, and held this position to the time of his death, July 29, 1906. He was a member both of this Society and of the American Institute of Electrical Engineers, and took an active interest in mechanical and electrical affairs.

FREDERICK BROTHERHOOD

Frederick Brotherhood was born in England in 1845 and was educated at private schools.

Later he entered Rowland Brotherhood Railway Works, Chippenham, England, working in the different departments, drawing office, shops, construction of bridges, railroad fittings and rolling stock, locomotives and general engineering, and later assisted in the building of various railroads and executing contracts.

He was superintendent of the Wilkesbarre Shops of the Dickson Manufacturing Company two years, with the Charleston Iron Works, Charleston, S.C., in the designing and construction of boilers, engines and cotton compresses, six years, and since, as consulting engineer, he has designed and built various factories, dredges and dock gates. He operated successfully for many years one of the largest phosphate dredges ever built. Mr. Brotherhood died November 15, 1906, at Bridgeport, Conn.

EDWARD PAYSON BULLARD

Edward Payson Bullard was born August 18, 1841, in Uxbridge, Massachusetts. After the completion of his apprenticeship at the Whitin Machine Works, Whitinsville, Mass., until 1863 he was connected with the Colts Armory in Hartford, Conn., after which he entered the employ of Pratt and Whitney, and later formed the partnership of Bullard and Prest, Machinists of Hartford. In 1866 Mr. Bullard organized the Norwalk Iron Works Company of Norwalk, Conn., but afterward withdrew and continued the business in Hartford. In 1868 the firm of Bullard and Prest dissolved and Mr. Bullard became superintendent in a large machine shop at Athens, Georgia. Later he became connected with the Cincinnati branch of Post and Company, organizing their machine tool department.

In 1872 he was made general superintendent of the Gill Car Works, Columbus, Ohio; in 1875 established himself in the machinery business on Beekman Street in New York, under the firm name of Allis, Bullard and Company and in 1877 the Bullard Machine Company was organized. In 1880 Mr. Bullard secured entire control of the business. Later in the same year he became the owner of the Bridgeport Machine

Tool Works. In 1883 he designed a 37 inch vertical boring and turning mill with single head and belt feed, which is believed to be the first small mill of this type.

The Bridgeport Machine Tool Works was incorporated in 1894 under the name of the Bullard Machine Tool Company, with which Mr. Bullard was connected at the time of his death, December 22, 1906.

JAMES ABERCROMBIE BURDEN

MR. BURDEN was born in Troy, N. Y., January 6, 1833. In his early youth he gave evidence of his mechanical and engineering genius. He received his education in Sheffield Scientific School, Yale, and the Rensselaer Polytechnic Institute. He went into the works to learn the iron business, and his wonderful executive ability and organizing genius, which later won for him the rank of Captain of Industry, became apparent.

He was an inventor of several devices for iron manufacture, and held 18 patents of his inventions.

Mr. Burden was interested in many charities, and as a man and citizen he took an active part in political and philanthropic affairs. He could never be induced to accept a public office, but was Presidential Elector for two Presidents. In addition to his ownership of the great iron manufactory he was a member of the Stanton Steamer Company. He gave financial aid in the building of churches and hospitals, and was greatly interested in the Benevolent Association, which bears his name.

He was a member of the American Society of Civil Engineers, The American Institute of Mining Engineers, as well as of this Society. He was a member of many clubs and leagues in America, and also of several engineering and scientific societies in England. He was the first President of the Engineers' Club, and was a member of the New York Chamber of Commerce and American Museum of Natural History. At the time of his death, which occurred September 24, 1906, in Troy, N. Y., while he was President of the Burden Iron Company.

HOBART CANFIELD

Hobart Canfield was born in 1841 in Morristown, N. J. He was educated in the schools of that city and began his apprenticeship with the Speedwell Iron Works, continuing with the Canfield & Lidgerwood Machine Shop until 1859. His shop experience was gained with the above named company and in erecting marine engines with the Novelty Iron Works, New York.

From 1860 to 1865 he erected sugar, coffee, and cotton machinery, and from 1868 to 1872 was with the Pacific Mail Co. leaving them to accept a position on dry dock work at the Mare Island Navy Yard, and remaining there until 1876. He became associated with the Pennsylvania Railroad Company as master mechanic of their Hoboken shops in 1877, and held this position to the time of his death, November 15, 1906, directing the operations of the shop which is employed on the maintenance and repairs of the entire floating equipment used by the Pennsylvania Railroad Company in the New York harbor. During this period, Mr. Canfield inaugurated many improvements in shop methods and developed a great many features that adapt the equipment to the peculiarities of harbor transportation.

He was widely known among the marine interests in New York harbor, and highly respected for his professional attainments.

He was elected a member of the Society in 1892.

MICHAEL JOSEPH DALY

Michael Joseph Daly was born in South Norwalk, Conn., December 20, 1840. His early work as a mechanic was with Pitkin Bros. & Co. of Hartford, in charge of important contracts. In 1882 he began business for himself with a limited capital, but gradually the small works became prominent in mechanical construction in New England, mainly in steam plants for churches, libraries, and similar institutions. Mr. Daly was active in church and municipal affairs, a member of the Master Steam Fitters' Association, and has been a member of the Society since 1899. His death occurred in Waterbury, Conn., January 11, 1906.

EDWARD THOMAS HANNAM

Edward Thomas Hannam was born February 16, 1861, at Baltimore, Md. He was educated in the public schools at Baltimore and served his apprenticeship in the Mt. Clare Shops of the B. & O. R. R., becoming in 1883 chief draftsman of the Trans-Ohio Division. In 1885 he accepted a position in the drafting room of the Barney & Smith Car Works at East Buffalo, N. Y. From 1887 to 1906, he occupied positions as mechanical engineer with the Cumberland & Pennsylvania R. R., Mt. Savage, Md., superintendent of the Kingsland & Douglas Mfg. Co., St. Louis, Mo., mechanical engineer and draftsman for Meier & Foster, and the Heine Boiler Co., St. Louis, Mo., mechanical engineer and agent for the Hawley Down Draft Furnace Co. of Chicago, Ill., and secretary and general manager of the Ohio Territory of the same company. He became manager of

the Ci i District for Ci 901, and was
th the Atlas s in 1904.
. Ha invented A ter tube boiler, and superin-
tended its l i until , hen he was appointed manager
of the Pl t s Engine Works, and remained
in this p a un 19 ecame manager of sales of the
water tu i of me works, which position he
held l a Aug 1 , at Chicago, Ill.

WALLACE C. JOHNSON

Wallace C. Johnson w b in 1859 in Granville, Mass. He graduated from Willia Co 1882 with the degree of M.A., and took a post g orcester Polytechnic Institute, receiving in 1884 the ee B.S. His professional career began as assistant engineer of the hy epartment, Holyoke Water and Power Co., and he subseq y oc upied the following positions: Chief Engineer, Niagara Falls Hyd lic Power and Mfg. Co. 1886–1900; 1900–1905, Chief Engi winigan Water and Power Co., Montreal, Can.; 1905–1906, Cl E eer, Bodwell Water Power Co., constructing a hydro-electric the Penobscot River at Old Town, Me. Since 1884 he has m e many examinations and reports upon hydro-electric propositions in d ferent parts of the country.

Mr. Johnson was a member of the S ate Water Supply Commission of New York, President Shawinigan Terminal Railway, Vice-President Albion Power Co., director Lav al Electric Co., consulting engineer Niagara Falls Hydraulic Pov nd Mfg. Co., Shawinigan Water and Power Co., Hannawa Falls Wa Power Co., Pittsburg Reduction Co., Milford Construction Co., Buxto n Power Co.

He was a member of the Ameri an Society of Civil Engineers, Canadian Society of Civil Engineers, American Institute of Electrical Engineers, Past President Engineers' Society of Western New York, member of the Society of Arts (London), St. James Club (Montreal), University Club (Buffalo).

PETER E. LE FEVRE

Peter E. Le Fevre was born at Brooklyn, N. Y., on November 26, 1841. After receiving his education he became a marine engineer He was chief engineer of the following steamships: The North America, South America, Matanzos, Merrimac, Herman Livingston, City of Macon, City of Columbus, and Tallahassee.

From 1887 to his death he was superintending engineer of the

Ocean Steamship Company and the Canada and Atlantic Steamship Company, being responsible for all work on steamers and docks.

Mr. Le Fevre became a member of the Society in 1895. He died in New York, November 19, 1906.

PETER WILLIAM LÜDERS

Peter William Lüders was born March 22, 1872 in Schleswig-Holstein, Germany. He began practical work early, his first mechanical experience being gained in the machine shops of the Berliner Maschinenbau Artiengesellschaft. In 1891 he entered the Polytechnical High School at Carlsruhe. In March 1899 he left Berlin and came to the United States with the purpose of making a special study of American machine shop practice, spending several months in some of the most important shops. He was elected an Associate Member of The American Society of Mechanical Engineers in November 1899; was a contributor of articles to the Engineering Magazine on American machine shop practice from a German view point. After his return to Berlin in the year 1901 Mr. Lüders became a member and general superintendent of the Berlin Erfurter Maschinenfabrik, Henry Pels and Company. The success of his work in bringing the shops up to date for the manufacture of the punching and shearing machines of the Berlin Erfurter Maschinenfabrik is due to his untiring energy and perseverance.

Mr. Lüders died June 30, 1906.

CARLETON WALWORTH NASON

Carleton Walworth Nason was born in 1849 in Woburn, Mass. He was educated in the New York schools and Columbia School of Mines. He entered business life early, and in 1872 became vice-president of The Nason Mfg. Co., and took entire charge of the business in 1884.

Mr. Nason advanced the art of steam heating and steam fitting by many important inventions. Among these were the pneumatic lift and the sheet iron diaphragm of a radiator, running almost the length of the tube, the design now used largely by the U. S. Navy. Mr. Nason also designed a wrought iron boiler for house heating, which is notable for its high efficiency. He patented few of his inventions.

In 1884 Mr. Nason was Chairman of a Committee representing this Society which worked in conjunction with representatives of manufacturers and contractors for the adoption of a schedule of standard flanges for pressures up to 200 pounds and for pipe sizes from 2 to 48

inches. For many years he served on the Committee of the General Institute of Mechanics and Tradesmen.

Mr. Nason became a member of the Society in 1880, and served as Manager on the Council 1889–1892. He was President of the Motor Cycle Club, a member of New York and Atlantic Yacht Clubs and Eastport County Club. He died November 4, 1906.

WILLIAM PAINTER

William Painter was born in Philadelphia, November 20, 1838. He adopted the profession of mechanical engineering in 1861, and from that time interested himself in inventions with the result that before his death he received nearly one hundred patents.

In 1882 he began inventing appliances used in bottling, and perfected the crown cork, loop seal, and the aluminum bottle stopper, as well as the machinery used in their manufacture. Mr. Painter was secretary and general manager of the Bottle Seal Company from 1882 until 1892, at which time the Crown Cork Seal Company was incorporated as the successor of the Bottle Seal Co. He continued in the position of secretary and general manager until January, 1903. Mr. Painter was a member of the American Institute of Mining Engineers, a life member of the Maryland Academy of Sciences, and a prominent and active member of several Baltimore clubs. He had been ill since June 1, and died July 15, 1906, at the Johns Hopkins Hospital.

CHARLES WALTER PHIPPS

Mr. Phipps was born in Worcester, England, on January 5, 1859, came to America when a youth, and soon became associated with the Brush Engineering Company of Cleveland, Ohio.

In later years he was identified with important electrical developments of the time, among which were the original installations of the arc light in England, China, and Japan. In the latter case it was the first electrical apparatus of any kind installed in that country.

After several years absence in the far East, Mr. Phipps returned to America and became Manager of the Brush Company; he was later associated with the Adams-Bagnall Electrical Company, manufacturers of arc lamps. In 1891 he was made Manager of British-Thompson, Houston Co. at Rugby, Eng., which position he held until his death, August 31, 1906.

Mr. Phipps became a member of the Society in 1892.

SIR EDWARD J. REED

Sir Edward J. Reed, K.C.B. and M.P., died November 30, 1906. He was born in 1830 at Sheerless, Kent, England, and educated at the School of Mathematics and Naval Construction at Portsmouth. Sir Edward received his appointment as Chief Constructor of the British Navy in 1863, but at the end of seven years resigned because he did not favor rigged sea-going turret ships which were then so much in favor. From 1874 to 1895, he was a member of Parliament and was made Lord of the Treasury in 1886. At one time he was editor of "The Mechanics Magazine." He was the author of several books, notably "The Stability of Ships" and "Modern Ships of War;" was Vice-President of the Institute of Naval Architects, and a former member of the council of the Institution of Civil Engineers. Sir Edward was elected an Honorary Member of The American Society of Mechanical Engineers in 1882.

VERNON H. ROOD

Vernon H. Rood was born in Elyria, Ohio, Nov. 10, 1856, and died in Bad Manheim, Germany, Sept. 2, 1905. He graduated at Stevens Institute of Technology with the Class of '82, and shortly afterward accepted a position as assistant to the superintendent of J. C. Haydon & Co., builders of mining machinery at Jeanesville, Pa. From 1882 to 1884 he was draftsman with Coxe Bros. & Co., at Drifton, and occupied a similar position with the Philadelphia and Reading Coal & Iron Co., at Pottsville from 1884 to 1887. In 1887 he became associated with the Barr Pumping Engine Co. of Philadelphia, remaining with them until 1890, when he was made vice-president and manager of the Jeanesville Iron Co., Hazelton, Pa., and held this position until his death.

Mr. Rood became a member of the Society in 1886.

JAMES ROWAN

James Rowan was born in Glasgow on March 18, 1854. He was educated at the Glasgow Academy and the Glasgow University, serving subsequently an apprenticeship of five years (from 1870 to 1875) in the pattern shop, the fitting department and the drawing office of his father's works. In 1880, he became assistant manager, and five years later was made a partner, the title of the firm becoming David Rowan and Son. In 1888 he assumed complete control of the establishment. He evolved the Rowan premium system applied to shop

management and delivered addresses before several engineering conferences on works organization and labor remuneration.

Mr. Rowan took an active and useful part in many engineering organizations. He was a member, sometime a vice-president, and at the day of his death a member of the Council of the Institution of Mechanical Engineers. He was a member of the Northeast Coast Institution of Engineers and Shipbuilders, and was president for the current year of the Northwest Engineering Employers Association.

Mr. Rowan died November 19, 1906.

LOUIS SCHUTTE

Louis Schutte was born in 1842 in Hamburg, Germany. He attended the Polytechnic College, Hanover, graduating in 1862. He began his business career in Hamburg, later going to Berlin, and from there to London, progressing from the position of draftsman to that of superintendent. Arriving in the United States in 1670, he established a company for the manufacture of injectors of the Koerting type and later added to this branch the manufacture and sale of special and automatic valves, which are known in America under the name of Schutte valves.

At the time of his death Mr. Schutte was president of the Schutte and Koerting Company. He was a member of the Union Republican Club, the Union League Manufacturers' Club, the Engineers' Club, and became a member of the Society in 1887. He died in September, 1906.

GEORGE FREDERICK STILLMAN

George Frederick Stillman was born April 11, 1858. He was educated in the public schools and at Cazenovia Seminary, and gained his shop experience at the works of E. Remington & Sons; Saginaw Mills and Ship Yard. He was assistant to Prof. Charles I. King, University of Wisconsin, and superintendent of The Lake City Tool Company. He returned later to E. Remington & Sons to the department of model and tool making. He became superintendent of shops of Smith & Weston of Syracuse and later entered the employ of The Smith Premier Typewriter Company as tool maker and was made superintendent of the factory. He was thoroughly familiar with not only the machine part of the business, but invented many details of the machine and devised ways and means to reduce the cost of production. He made several inventions outside of his improvements on the typewriter, one of these being a measuring machine, in which he introduced an ingenious method of correcting

the pitch of the master screw. He was also one of the inventors of the clincher type of bicycle tire, which eventually came out as the Dunlap type.

Mr. Stillman became a member of the Society in 1904. He died December 2, 1906.

WILLIAM DURELL STIVERS

William Durell Stivers was born in Jersey City, N. J., February 20, 1871. He received his education in the public schools, graduated from the high school in 1887, and pursued some special studies in mechanical engineering at the Cooper Institute in New York. He entered the DeLamater Iron Works in 1887 and was assigned to special service in the superintendent's office where he had unusual opportunity for acquiring a special training in shop management, engineering and experimental work. While there he took part in various interesting experiments that were conducted at the DeLamater Iron Works, as, for instance, those of the noted Ericsson expansion engine, the hot air engine, the Belleville boiler, refrigerating and compressed air machinery, and other constructions. After the dissolution of the DeLamater Iron Works in 1889, Mr. Stivers entered the Quintard Iron Works as draftsman, eventually rising to the position of acting superintendent. He supervised the building and installation of the machinery of the U. S. S. "Maine" which was destroyed in Havana Harbor. He was the works representative on the trial trips of the U. S. S. "Concord," "Bennington," "Detroit" and "Marblehead." He also had a prominent part in the trial trip of the U. S. S. "Bancroft." In 1902 he left the Quintard Iron Works to accept the position of superintendent of the Yonkers Works of the Otis Elevator Company, which position he held until March, 1904, when he was engaged by the C. W. Hunt Co. as executive engineer, remaining active in that place until his death in December, 1906. He joined the Society in 1904.

WILLIAM CHRISTOPHER TURNER

William Christopher Turner was born in Philadelphia, Pa., 1856, and educated in public and private schools in that city. He became general manager and superintendent of the Delaware and Chesapeake Improvement Co. of Philadelphia, remaining with them six years. He was for some time with the Link Belt Engineering Co. and later became associated with the C. W. Hunt Co. and the Caslin Machine Co. of New York. He accepted a position with the Babcock &

Wilcox Company, representing them in the South, and later became supervisor of the machine boiler department. In 1904 Mr. Turner was one of the organizers and vice-presidents of the Daldt Steel Co. of New Castle, Del., and was an officer of this corporation until the time of his death July, 1906.

Mr. Turner became a member of the Society in 1881.

BENJAMIN HOWARD WARREN

Benjamin Howard Warren, a member of the Society since its organization in 1880, and a Vice-President from 1898 to 1900, died in New York, October 20, of cerebral apoplexy. He was born in Dorchester, Mass., February 19, 1850, being the elder son of the late Captain Moses H. Warren, who commanded Company I of the First Massachussetts Volunteers at Spottsylvania, where he was killed May 12, 1864. His mother was Ann M. (Longley) Warren of Boston, who died November 13, 1905.

Mr. Warren was graduated from the United States Naval Academy in 1874, in the class of engineers, and was placed on the retired list June 11, 1878, on account of partial deafness. He then entered the employ of the Hancock Inspirator Company, and about four years later took charge of their works. From 1890 to 1895, he was manager of the crane department of the Yale & Towne Mfg. Co., Stamford, Conn., and was later Secretary and Treasurer of the Pratt & Whitney Company, Hartford, Conn. In 1896 he entered the service of the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa. as assistant general manager and was shortly afterwards made vice-president. In 1904, he became president of the Allis-Chalmers Company, bringing under one executive head the various companies and allied interests controlled by it. In January, 1906, he formed a partnership with two of his old friends, John C. Kafer and Asa M. Mattice, as consulting engineers, under the firm name of Kafer, Mattice & Warren. Mr. Kafer died soon after the forming of the partnership.

Mr. Warren was a member of the Society of Naval Architects and Marine Engineers, the American Society of Naval Engineers, the Loyal Legion, the Engineers' Club, the University Club of New York and the Lawyers' Club.

For a number of years past his home has been in Alberene, Virginia, where he had a large estate. He leaves a widow, formerly Miss Elizabeth R. Mitchell of Quincy, Mass., two daughters, and a son, a recent graduate of Harvard. He is survived also by his brothers, Arthur Warren, of the editorial staff of the "Boston Herald," and by his sister, Mrs. Thomas E. Ewing of Dorchester, Mass.

Funeral services were held at the Church of the Incarnation, New York, and the remains were then taken to Quincy, Mass., and interred in Mount Wollaston Cemetery.

Wilcox Company, representing them in the South, and later became supervisor of the machine boiler department. In 1904 Mr. Turner was one of the organizers and vice-presidents of the Daldt Steel Co. of New Castle, Del., and was an officer of this corporation until the time of his death July, 1906.

Mr. Turner became a member of the Society in 1881.

BENJAMIN HOWARD WARREN

Benjamin Howard Warren, a member of the Society since its organization in 1880, and a Vice-President from 1898 to 1900, died in New York, October 20, of cerebral apoplexy. He was born in Dorchester, Mass., February 19, 1850, being the elder son of the late Captain Moses H. Warren, who commanded Company I of the First Massachussetts Volunteers at Spottsylvania, where he was killed May 12, 1864. His mother was Ann M. (Longley) Warren of Boston, who died November 13, 1905.

Mr. Warren was graduated from the United States Naval Academy in 1874, in the class of engineers, and was placed on the retired list June 11, 1878, on account of partial deafness. He then entered the employ of the Hancock Inspirator Company, and about four years later took charge of their works. From 1890 to 1895, he was manager of the crane department of the Yale & Towne Mfg. Co., Stamford, Conn., and was later Secretary and Treasurer of the Pratt & Whitney Company, Hartford, Conn. In 1896 he entered the service of the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa. as assistant general manager and was shortly afterwards made vice-president. In 1904, he became president of the Allis-Chalmers Company, bringing under one executive head the various companies and allied interests controlled by it. In January, 1906, he formed a partnership with two of his old friends, John C. Kafer and Asa M. Mattice, as consulting engineers, under the firm name of Kafer, Mattice & Warren. Mr. Kafer died soon after the forming of the partnership.

Mr. Warren was a member of the Society of Naval Architects and Marine Engineers, the American Society of Naval Engineers, the Loyal Legion, the Engineers' Club, the University Club of New York and the Lawyers' Club.

For a number of years past his home has been in Alberene, Virginia, where he had a large estate. He leaves a widow, formerly Miss Elizabeth R. Mitchell of Quincy, Mass., two daughters, and a son, a recent graduate of Harvard. He is survived also by his brothers, Arthur Warren, of the editorial staff of the "Boston Herald," and by his sister, Mrs. Thomas E. Ewing of Dorchester, Mass.

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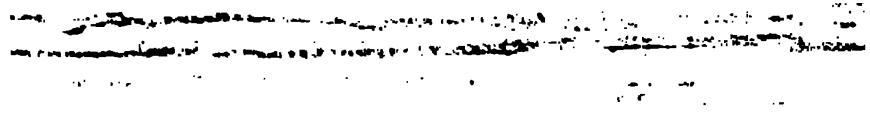

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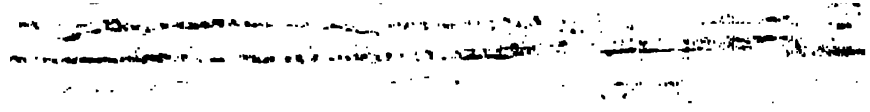

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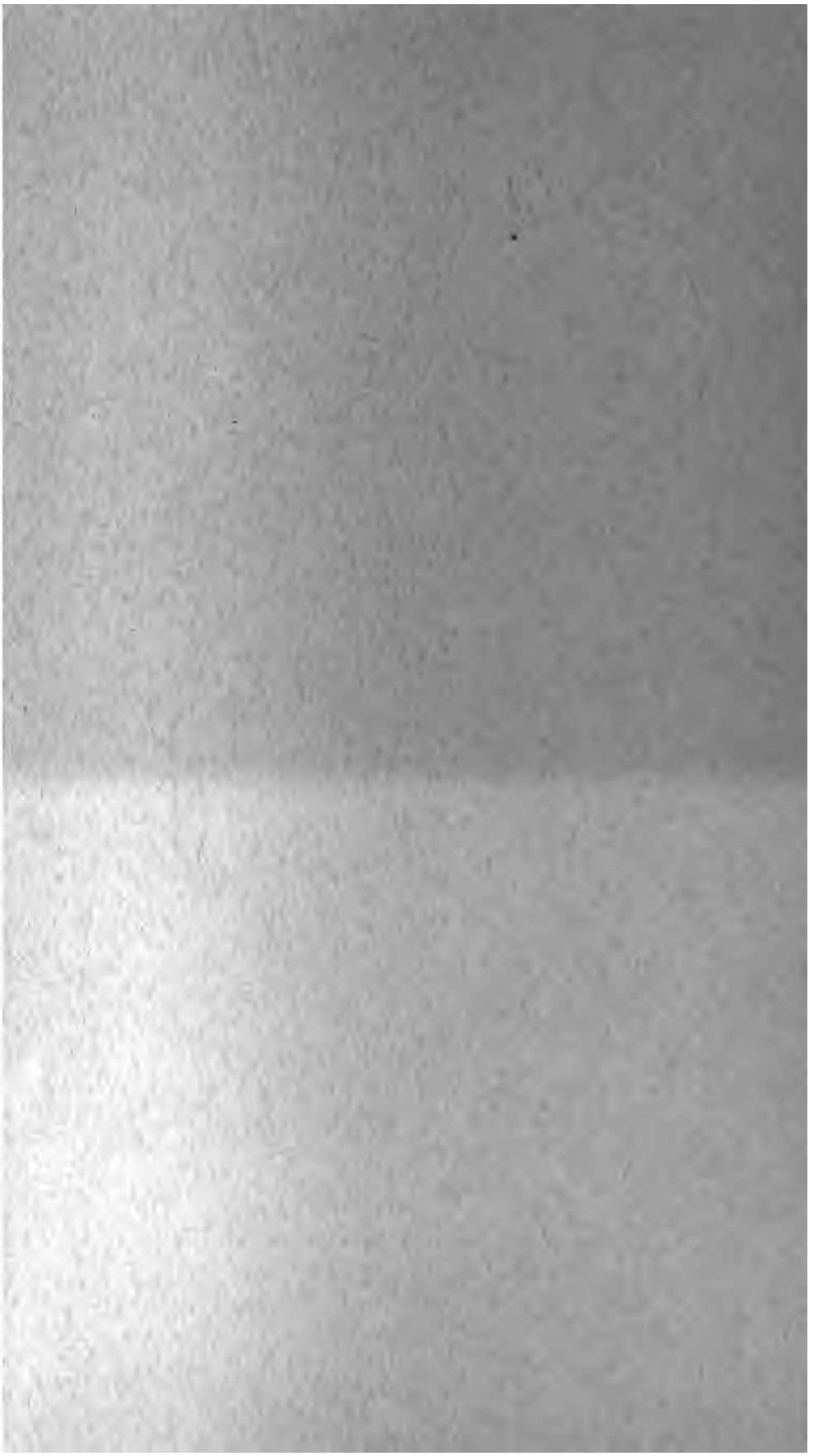

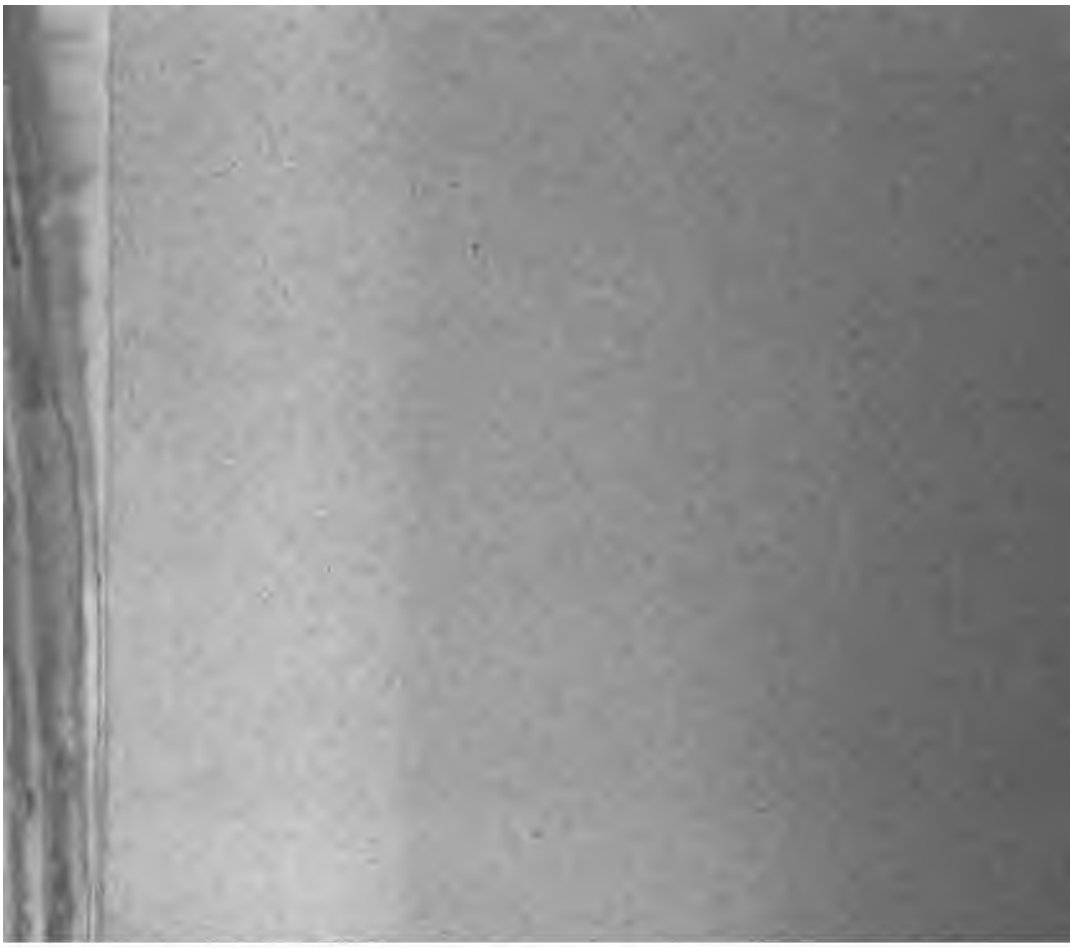

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